

Water Temperature, River Discharge, and Adult Sockeye Salmon Migration Observations in the Quesnel / Horsefly Watershed

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WATER TEMPERATURE, RIVER DISCHARGE, AND
ADULT SOCKEYE SALMON MIGRATION OBSERVATIONS
IN THE QUESNEL / HORSEFLY WATERSHED

by

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ABSTRACT

Stiff, H. W., K. D. Hyatt, T. E. Cone, D. A. Patterson, and K. Benner. 2018. Water temperature, river discharge, and adult Sockeye Salmon migration observations in the Quesnel / Horsefly watershed. *Can. Manuscr. Rep. Fish. Aquat. Sci.* 3154: vi + 196 p.

Historical meteorological, water discharge and water temperature data were assembled to review the influence of changes in these environmental factors on daily migration patterns of adult Sockeye enroute to the Horsefly River spawning grounds via the Quesnel River, a major tributary of the Fraser River, British Columbia. A standardized index of daily Sockeye migration was derived from adult migrant estimates from Quesnel and Horsefly visual and acoustic counts for 13 years between 1993 and 2015. A stratified categorical frequency analysis of daily water temperature and flow estimates versus the standardized migration index lagged 0-7 days earlier was used to discern the most likely combination of threshold values for temperature, discharge, and time lag contributing to variation in daily migration. The resulting critical thresholds were applied in exceedance analyses to review trends in flow and temperature events pertinent to Sockeye migration. Variations in two annual spawn timing indices (1940-2015) were correlated with reconstructed Quesnel and Horsefly monthly temperature and flow conditions to review environmental effects on spawner arrival date and peak spawn activity date.

Though trending slowly upward (0.1°C per decade) since the 1900s, mean August-September air temperatures and associated water temperatures in the Quesnel watershed (elev. 500-1000 m) remain cool, on average 15°C during Sockeye migration. The decline in Quesnel/Horsefly discharge during the Aug-Sep migratory period since the 1960s is statistically-significant. Low discharge levels in the Horsefly River were statistically associated with later timing of arrival on the spawning grounds and peak spawning. However, July mean flows are rising, reflecting a shift in the distribution and magnitude of peak flows, which may be contributing to migration delays, as high daily migration rates were generally inhibited until daily mean discharge dropped below 400 cms in the lower Quesnel River. Statistics from a non-parametric test of association between migration rate and environmental factors showed little effect due to temperature, but indicated flow conditions at a potential velocity barrier at Quesnel Canyon in the lower Quesnel River were most highly associated with categorical changes in migration rates at the counter site in the upper Quesnel River four days later.

RÉSUMÉ

Stiff, H. W., K. D. Hyatt, T. E. Cone, D. A. Patterson, et K. Benner. 2018.

Observations sur la température de l'eau, le débit fluvial et la migration du saumon sockeye adulte dans le bassin hydrographique des rivières Quesnel et Horsefly. Rapp. manus. can. Fish. halieut. aquat. xxxx : v + XX p.

Des données météorologiques et historiques sur le débit fluvial et la température de l'eau ont été recueillies afin d'étudier l'influence des changements de ces facteurs environnementaux sur les habitudes migratoires quotidiennes du saumon sockeye adulte en route vers ses frayères de la rivière Horsefly, en passant par la rivière Quesnel, qui est un affluent majeur du fleuve Fraser en Colombie-Britannique. Un indice normalisé de la migration du saumon sockeye a été calculé à partir des estimations de dénombrements visuels et acoustiques de spécimens adultes migrants provenant des rivières Quesnel et Horsefly, échelonnées sur 13 ans entre 1993 et 2015. Une analyse par fréquence des catégories d'estimations de la température de l'eau et des débits quotidiens par rapport à l'indice normalisé de migration (décalage de 0 à 7 jours plus tôt) a servi à déterminer la combinaison la plus probable des valeurs des seuils de la température, de l'écoulement et des décalages connexes contribuant à la variation de la migration quotidienne. Les seuils critiques obtenus ont été appliqués dans des analyses des dépassements afin d'étudier les tendances concernant le débit et la température qui peuvent être pertinentes à la migration du saumon sockeye. Des variations dans les deux indices sur la période de frai annuelle (1940-2015) étaient en corrélation avec les conditions de débit et de température mensuelle reconstituées des rivières Quesnel et Horsefly afin d'examiner les effets environnementaux sur la date d'arrivée des reproducteurs et la date de pointe du frai.

Malgré une tendance lentement à la hausse (0,1 °C par décennie) depuis les années 1900, les températures moyennes de l'air d'août à septembre et les températures de l'eau qui y sont associées dans le bassin hydrographique de la rivière Quesnel (élévation de 500 à 1 000 m) demeurent fraîches, en moyenne 15 °C durant la migration du saumon sockeye. La baisse de l'écoulement des rivières Horsefly et Quesnel, au cours de la période de migration d'août à septembre, est statistiquement significative depuis les années 1960. Les faibles niveaux d'écoulement dans la rivière Horsefly étaient statistiquement associés au retard de l'arrivée dans les frayères et du pic de la période de frai. Cependant, l'écoulement moyen de juillet est à la hausse, ce qui reflète un changement de la répartition et de l'ampleur de l'écoulement de pointe, pouvant contribuer à une migration tardive, parce que les taux élevés de migration quotidienne ont été généralement freinés jusqu'à ce que l'écoulement quotidien moyen descende sous la barre des 400 cm/s dans la partie inférieure de la rivière Quesnel. Les statistiques, tirées d'un test d'association non paramétrique entre le taux de migration et les facteurs environnementaux, démontrent un effet limité de la température, mais elles indiquent que les conditions du débit sont un obstacle possible à la formation de courant au canyon Quesnel, situé dans la partie inférieure de la rivière Quesnel, et qu'elles étaient principalement associées à des changements catégoriques dans les taux de migration au site de dénombrement situé dans la partie supérieure de la rivière Quesnel quatre jours plus tard.

INTRODUCTION

Maintaining healthy and diverse populations of salmon that will support sustainable fisheries in the present and for future generations is a key goal of the Department of Fisheries and Oceans' WILD SALMON POLICY (FISHERIES AND OCEANS CANADA 2005). This goal is advanced by safeguarding the genetic diversity of wild salmon populations, maintaining habitat and ecosystem integrity, and managing fisheries for sustainable benefits.

However, management methods to meet sustainable fisheries and biodiversity objectives are likely to be affected by climate change impacts on the distribution, abundance, and productivity of wild salmon populations (Finney et al. 2002). Therefore, conservation, restoration, and harvest management of many wild salmon populations will require improvements in knowledge of the extent to which human disturbance versus natural disturbance events control variations in salmon production and biological traits (e.g. growth, survival, spawn timing, size and age at maturity etc.).

Within the general category of natural disturbance regimes or events, annual and seasonal variations in temperature and flow represent the most common factors exerting a major influence over salmon life history outcomes in freshwater. Analyses of historical data indicate that significant changes in regional meteorological factors (such as air temperature and precipitation) that directly affect freshwater quantity and quality have already occurred in response to climate change in Canada's Pacific region (e.g. Whitfield and Cannon 2000; Whitfield 2001; Whitfield, Bodtker, and Cannon 2002), and regional climate model projections point to increased changes in these factors through the 21st century (Abdul-Aziz, Mantua, and Myers 2011; Littell et al. 2011; Stiff, Hyatt, and Cannon 2018).

Recent investigations in the Pacific Northwest and British Columbia have demonstrated regional air temperature shifts of about 0.8°C over the past century, with projected temperature increases of 1.5-3.2°C in near-future decades (Mote et al. 2003). Seasonal precipitation has also changed markedly in the recent past (Walker and Sydneysmith 2008), and future projections point to wetter winters and drier summers, with a high likelihood that extreme events involving regional temperature and precipitation will become more frequent (Mantua, Tohver, and Hamlet 2010; IPCC 2014). These analyses also indicate that the magnitude and direction of historical and projected climate variability exhibit sub-regional specificity due to the large and topographically complex areas involved (Walker and Sydneysmith 2008; Fleming and Whitfield 2010; Fleming et al. 2016).

Temperature effects on migrating adult Sockeye (*Oncorhynchus nerka*) have been well documented in many river systems in the Pacific Northwest and British Columbia (Hyatt et al. 2003; Nelitz, Alexander, and Wieckowski 2007; Salinger and Anderson 2006). Lethal temperatures are reported in the range 21-24°C (Servizi and Jensen 1977), and water temperatures in excess of 18°C may affect migration speed, cause timing delays, and alter spatial distribution of Sockeye Salmon (Hyatt

et al. 2015; Pellett et al. 2015). Increased water temperature also may result in secondary effects such as increased disease, resulting in pre-spawn mortality (Cooke et al. 2004; Hinch and Martins 2011; Hyatt et al. 2016 in: Chandler et al. 2016). Thermal stress has also been found to reduce salmon fecundity, gamete viability, fertilization rates, and egg-to-fry survival rates (Jensen et al. 2004; Burt et al. 2012; Martins et al. 2012). Since Sockeye Salmon populations may also differ in their thermal tolerances, reflecting local adaptation to conditions over their historic evolution (Eliason et al. 2011; Thomson and Hourston 2011), stock-specific responses to climate variation and change impacts are also possible.

Stream discharge levels may also be associated with variations in migration timing, causing delays, affecting swimming speed, and inducing biological stress during upstream migration of adult salmonids (Hinch and Bratty 2000). The quantitative effects may differ between waterbodies due to unique physical stream attributes (rapids and falls, canyons, etc., but also man-made fishways and weirs) which influence water velocity in key locations along the migratory route (Pellett et al. 2015). In some cases, low flows may result in physical limits to fish passage; in other cases, high flows may generate velocity barriers that reduce or prohibit upstream migration (Hinch and Bratty 2000).

Trend analyses to date have identified increases of 2-3°C in the mean, minimum and maximum water temperatures of the Fraser River during the adult Sockeye migration period since the 1950s (e.g. Patterson et al. 2007). These changes are having associated impacts on Fraser Sockeye population health (Hinch & Martins 2011; Macdonald et al. 2000), fish condition (Hinch et al. 2002), and fisheries management (Hague & Patterson 2007). Further studies show that adult migrants encounter a range of temperature and flow conditions in the remote tributaries of their freshwater migration route that may not be consistently well-correlated with lower Fraser conditions – especially for populations returning to spawning grounds in excess of 500 km from the marine environment (Hague, Patterson, and Macdonald 2008). As Hague et al. state (2008, p. vii): *“These results provide a rationale for further exploration into the use of multi-site, alternate-site, and cumulative exposure models to better reflect the full impact of freshwater conditions on the health and spawning success of Fraser River Sockeye Salmon populations.”*

This report documents the data assembled for derivation of historic water temperature and flows affecting Quesnel Sockeye Salmon on the final leg of their migration to the spawning grounds in the Horsefly watershed. It is one of a series of manuscripts intended to consolidate and document historic observations on key life history events and associated environmental variables for relatively data-rich Sockeye and Chinook salmon populations distributed throughout their range in Canada's Pacific region (Hyatt et al. 2015; Stiff et al. 2013; 2015a; 2015b; 2015c; Damborg et al. 2015). Although there are many potential uses for these data, the focus of our current work is to develop lifestage-specific models that identify potential associations between salmon production variations and climate variation effects in freshwater and marine ecosystems throughout the eastern rim of the north Pacific.

STUDY AREA

Location

The Quesnel River is a major tributary to the Fraser River, British Columbia (Figure 1). The watershed drains approximately 11,500 sq. km of the CENTRAL INTERIOR eco-province via multiple lacustrine sub-basins (Quesnel, Horsefly, Cariboo, Mitchell) with headwaters originating at elevations up to 2,500 m in the western edge of the CARIBOO MOUNTAIN range (Figure 2). The watershed drains north and west out of the QUESNEL HIGHLANDS onto the FRASER PLATEAU, and ultimately into the FRASER BASIN at the City of Quesnel (Child & Millar 1997).

Secondary roads service small settlements, such as the towns of Likely and Horsefly, and the resorts and summer cabins that populate many of the lakes. Logging and mining activity has occurred throughout much of the landscape outside of park areas (Demarchi 2010). Mountain pine beetle infestations have severely impacted forests in this area since 1994. The Quesnel Lake and River system has also been subjected to one of the largest, human-induced, mass-wastage events in Canadian history. In August of 2014, a partial breach of a tailings pond at the Mount Polley open pit copper and gold mine released 10 million cubic meters of water and 4.5 million cubic meters of mine-tailings slurry that carried felled trees, mud and debris down Hazeltine Creek into Quesnel Lake (Figure 3).¹

Sockeye Migration

The Quesnel watershed supports one genetically-distinct Sockeye population², the QUESNEL-S population^{3,4}, part of the aggregate 'Summer-run' DFO management group. This population exhibits a quadrennial escapement cycle, characterized by extreme inter-annual variation in stock abundance on a 4-year cycle, with dominant cycle years beginning in 1901...1997, followed by a sub-dominant cycle line (1902...1998), and two 'off-cycle' lines (Cass 1998). During the 1980s and 1990s, the dominant year Quesnel stock comprised up to 48% of the total Fraser River Sockeye escapement (Cone 1999).

Sockeye spawn at numerous watershed locations in three sub-areas: Horsefly River and tributaries; Mitchell River and tributaries; and along the lakeshore and in tributaries of Quesnel Lake (Figure 3, Figure 4). Of the ~100 QUESNEL-S spawner sub-populations, twelve locations comprise almost 99% of total annual escapement

¹ https://en.wikipedia.org/wiki/Mount_Polley_mine_disaster

² Chinook, Coho, Bull Trout, Rainbow Trout, and Kokanee are also found in the Quesnel watershed (Nelitz et al. 2007).

³ Two Sockeye conservation units were originally distinguished in Holtby & Ciruna (2007): MCKINLEY-S for fish returning to the upper McKinley Creek tributary of McKinley Lake; and QUESNEL-S, representing all other spawning locations. More recently, the McKinley sub-group has been incorporated into QUESNEL-S (Grant et al. 2011).

⁴ The status of QUESNEL-S Sockeye is currently designated in the AMBER/RED ZONE by DFO and listed as LEAST CONCERN by the IUCN in 2011 (<http://www.iucnredlist.org/details/201451/0>).

abundance since 1990 (Appendix A)⁵. Of these, Sockeye bound for the Horsefly system and its tributaries (i.e. Horsefly Lake, Little Horsefly River, McKinley and Moffat Creeks), account for 63-88% of total Quesnel Sockeye escapement during the dominant cycle (Cone 1999).⁶ In 2010, Horsefly counts comprised a smaller proportion (56.5%) of the Quesnel total during a sub-dominant cycle line return as indicated by a single year of acoustic counts at both upper Quesnel and lower Horsefly sites.

From 1989 to 2005, the Horsefly watershed supported spawning populations in excess of 500,000 fish in both the dominant (1993) and subdominant (1994) cycle years (Appendix E). However, since 2009, spawner abundance has declined to sub-average quantities on all cycle lines.

Sockeye Salmon bound for the Horsefly watershed leave marine waters and enter the Fraser River beginning in late July (peak entry ~August 2nd)⁷ on a 760 km, 28-day journey to the spawning grounds. Migrating up the Fraser at approximately 40 km/d, Quesnel/Horsefly Sockeye swim the first 565 km from the Fraser estuary to the Quesnel River confluence over an elevation rise of approximately 470 m at an average climb ratio of 0.75 m/km.⁸

Sockeye then ascend approximately 260 vertical meters over the next 100 km to Quesnel Lake (elevation: 730 m) at an average climb ratio of 2.6 m/km (Figure 2). In the lake, Horsefly-bound fish swim 20-25 km to the outlet of the Horsefly River, and then ascend another 40 meters elevation through the lower Horsefly River (elevation: 768 m; Holtby & Ciruna 2005). Key Sockeye spawning habitat in Horsefly River is found between Sucker Creek and Deerhorn Creek and from Tisdall Creek to Horsefly waterfalls. Migrants bound for the upper Horsefly and McKinley Creek spawning grounds (elevation: 865 m) continue to climb at approximately 2.4 m/km.

Median migration timing past the upper Quesnel River counting sites near the community of Likely is September 2nd (Figure 4). Horsefly sockeye spawning extends over approximately a 6 week period, with the peak of spawning activity occurring by the second week of September.

⁵ Twelve sites account for up to 99% of Quesnel Sockeye spawning abundance: Horsefly Spawning Channel, Horsefly River (Lower, Upper, and Above Falls), Little Horsefly River, Lower and Upper McKinley Creek, Mitchell River, Cameron Creek, and Penfold Creek (Grant et al. 2011).

⁶ In 2010, when acoustic counters were installed at both upper Quesnel and lower Horsefly sites, Horsefly counts comprised 56.5% of the Quesnel total.

⁷ Time-to-50% at Hell's Gate: ~August 17th (Patterson et al. 2007).

⁸ Summer Sockeye swim speeds calculated for the Fraser portion range from 32-52 km/d (Killick 1955; Hague, Patterson & Macdonald 2008). Other sources indicate average swim speeds of 27 km/d from Fraser mouth to spawning grounds (Horsefly River Salmon Festival brochure), potentially reflecting slower swim speeds in the Quesnel system.

The Horsefly River is accessible to Sockeye upstream of the confluence at Quesnel Lake to an impassable cascade (Horsefly River Falls⁹) approximately 63 km above the river mouth, and includes an artificial spawning channel¹⁰ which is capable of accommodating 23,000 Sockeye (Cone 1999)¹¹. Spawning Sockeye populations are also found in Horsefly tributaries, including: Little Horsefly River, Moffat Creek (to the falls at ~8 km), and McKinley Creek into the headwaters (Figure 3, Figure 4).

Physiography and Biogeoclimatology

The QUESNEL HIGHLAND ECOSECTION rises from the Fraser Plateau to the rugged Cariboo Mountains to the east. The area is underlain by sedimentary and volcanic rocks. Glaciation rounded the summits and left cirque basins on north faces. Quesnel Lake is the largest lake in the ecosection, but others of note are: Horsefly, Cariboo, Crooked, Hobson and Clearwater lakes (Demarchi 2010).

The area has a semi-arid, sub-continental climate: cold winters, warm summers, and a precipitation maximum in late spring and early summer. Dry air masses from the lee of the Coast Mountains move east, accumulating moisture from wetlands, lakes and streams on the interior plateaus and releasing it over the western Cariboo and Rocky Mountains (Demarchi 2010). Precipitation therefore increases towards the eastern edge of the ecosection.

Total annual precipitation at QUESNEL¹², located in the slightly drier Fraser Basin on the western edge of the Quesnel watershed, is 394 mm, including 162 cm of snow (30-50% of total precipitation) (Table 1). Mean annual temperature is 5.5°C, ranging from lows of -7°C in winter to +16°C in summer. Late summer air temperatures during peak Sockeye migration periods (Aug-Sep) average 11-16°C, with typical maximums of 18-24°C, and total monthly precipitation of 40-50 mm (Figure 5). Peak monthly precipitation occurs in June and July, averaging 66 mm per month.

Cooler temperatures and moister air masses combine in this ecosection to promote two forested biogeoclimatic zones: the SUB-BOREAL PINE-SPRUCE zone with aspen and lodgepole pine (decimated by the pine beetle epidemic) in the south at lower elevations, and the INTERIOR CEDAR HEMLOCK zone at middle elevations in the Quesnel Highlands (Demarchi 2010).

⁹ Horsefly River Falls is a narrow 600-meter rock gorge situated approximately 5 km upstream of the McKinley Creek confluence. The principal falls is 8 m, with a secondary falls of 3 m, and the overall drop in the gorge is 30 m (Hamilton and Goodlad 1956).

¹⁰ Built in 1989, the Horsefly Spawning Channel provides an available spawning area of 15,200 m² and is designed to accommodate 12,500 females (Holmes 2009). The original objective was to rebuild Horsefly River Sockeye abundance in subdominant and off-cycle years, and provides a conservation function in the event of a catastrophic loss of eggs due to some natural event.

¹¹ The Horsefly River also provides spawning and rearing habitat for Chinook (*O. tshawytscha*), and Coho (*O. kisutch*) salmon. A late-maturing, biologically-distinct sub-species of Quesnel Lake Rainbow Trout (*O. mykiss*) spawn and rear in the Horsefly River watershed before migrating to Quesnel Lake. The river also contains populations of Mountain Whitefish (*Prosopium williamsoni*) (Moreau 2008).

¹² ENVIRONMENT CANADA meteorological station 1096630 QUESNEL A (elevation 545 m) climate normals 1981-2010 (Table 1, Figure 5).

Hydrology

Quesnel Lake (elev. 730 m) is an oligotrophic, dimictic, glacial fjord lake, 266 km² in area, with an average depth of 157 m and a maximum depth of 610 meters.¹³ The lake has a gross drainage area of 6,200 km² (Figure 3). The 98-km Horsefly River and its main tributaries (Little Horsefly River, Moffat and McKinley Creeks) drain an area of 2,400 km² (Figure 4). The Horsefly River includes a ten-metre-high waterfall about 55 kilometres downstream from the river's source. With a mean annual discharge (MAD) of 35 cubic meters per second (cms), the Horsefly is the major freshwater input to Quesnel Lake. Mitchell River, the next largest input (MAD: 12 cms), drains 245 km² of mountainous area into the north arm of Quesnel Lake.¹⁴

Quesnel River drains the main arm of the lake northwest for ~100 km to the Fraser River (elev. 475 m), dropping 250 m through the lower elevations of the Quesnel Highlands. It is joined by the Cariboo River (drainage area: 3,260 km²) at Quesnel Forks, ~15 km downstream of the lake outlet, nearly doubling the Quesnel River's discharge volume (Figure 3). The Quesnel has a meander length of 0.5 – 2.0 km (Helm et al. 1980). With the addition of several small stream inputs downstream of the forks, the combined MAD of the lower Quesnel River is approximately 240 cms, for a total drainage area of 11,500 km² (Table 2).

The hydrology of the Quesnel watershed is typical of interior, nival watersheds, with annual streamflow maxima corresponding to snow-melt events and rain storms in late spring and early summer (Nelitz et al. 2007). Maximum freshet in the Quesnel river system occurs in June and July following spring precipitation and upper elevation snowmelt and may exceed 1,000 cms (P75 ~ 700 cms). Glacier melt and attenuation by the numerous lakes in the region generally contribute to stable summer stream discharges, despite the absence of artificial water storage installations.¹⁵ The naturalized 7-day summer mean low flow is relatively high, exceeding 25% of the mean annual flow for streams in the Quesnel Highlands, and much higher for waterways with large headwater lakes such as the Quesnel and Horsefly (Rood & Hamilton 1995). Mean monthly flows typically decline over the summer, reaching a seasonal minimum in September. A secondary discharge peak can occur in October in some years due to heavy autumn rainfall.

High water velocities associated with canyons and rapids may be a hindrance to passage for adult salmon migrants at certain discharge levels. Two sets of rapids in the Quesnel/Horsefly system below the Horsefly River spawning grounds have been identified: Big Canyon (in the Quesnel River, approximately 14 km above the Quesnel/Fraser confluence), and Little Canyon (17 km further upstream). Of these,

¹³ https://en.wikipedia.org/wiki/Quesnel_Lake (downloaded: January 2016).

¹⁴ DFO/SEP built a flow-control weir at outlet of Mitchell Lake to manage water temperature and incubation flows for Sockeye in the Mitchell River, completed in 1989 (Rood & Hamilton 1995).

¹⁵ Natural glacier water storage and meltwater supply may not remain reliable as glaciers melt faster and diminish in overall size due to climate change (ibid). In addition, the effect of "beetle-wood" harvest management due to widespread Mountain Pine Beetle epidemic in this region may contribute to a shift in the timing and magnitude of annual peak flows (FPB 2007).

Big Canyon was identified as a 'hydrological challenge' to salmon by fisheries officers in the 1970s, though challenging discharge levels and corresponding dates were not specifically identified, and the site was simply annotated as 'passable' (Manzon & Marshall 1980). As site visits by fishery officers tend to be intermittent, or non-existent in low-cycle years, this only suggests that persistent migration delays and/or significant fish mortality due to high (or low) water velocity conditions were not consistently observed, and, therefore, it remains unknown to what extent, if any, these potential high velocity environments currently limit Sockeye migration.

Natural land-slides have occurred in the upper Quesnel River, as in 1976 and 1992, when a slide near Quesnel Forks blocked the river for several hours (Manzon & Marshall 1980; Rood & Hamilton 1995).

Cultural Importance

The Quesnel River system lies within the traditional territories and title lands of the NORTHERN SECWEPENC TE QELMUCW (NStQ) peoples, and Sockeye Salmon have been an integral cultural resource for food, social, and ceremonial purposes for centuries. The NORTHERN SECWEPENC TRIBAL COUNCIL (NSTC) fisheries department co-manages field operations and subsequent management of field data with the DEPARTMENT OF FISHERIES AND OCEANS (DFO) under an ABORIGINAL FISHERIES STRATEGY agreement. Currently, selective harvests for commercial purposes may occur (when fish abundance permits) for Sockeye, Chinook and Pink salmon harvested either by trap, beach seine or angling (QUESNEL SELECT)¹⁶. Experimental purse seine fisheries for Sockeye on Quesnel Lake occur during high cycle returns of Horsefly sockeye (ibid).

During the dominant and sub-dominant year cycles, Horsefly Sockeye and associated Quesnel Sockeye stocks also comprise a large proportion of British Columbia's lower Fraser and marine commercial, recreational, and subsistence fisheries, long before the fish arrive in the Quesnel watershed. Between 1985 and 1997, returns of Quesnel-bound Sockeye in the dominant cycle line averaged 10 million fish, and were harvested at an average rate of 78% (Cass 1998).

Recent History

Historically, Quesnel Sockeye returns were likely the largest of any Summer Run stocks, numbering, in some years prior to 1900, in excess of 10,000,000 fish (Cone 1999); escapement in 1909 was 4,000,000 (Babcock 1904 in Grant et al. 2011). Rapid declines in the early 1900s were a function of a number of factors, largely industrial (Nelitz et al. 2007). Mine waste tailings from placer mining operations were responsible for contaminated spawning grounds in both the Quesnel and Horsefly watersheds from the late 1800s through to the mid-1940s (Cooper 1956).^{17 18}

¹⁶ QUESNEL SELECT is a member of the INLAND SALMON PRODUCERS ASSOCIATION, which pertains to the conservation, certification and sustainable management of commercial First Nation fisheries in the Quesnel watershed: <http://www.riverselect.ca/fisheries/quesnel-select/>.

¹⁷ Placer mining operations downstream of Quesnel Lake (at Bullion Pit) likely had an adverse effect on fish and fish habitat in the area: an estimated 12,000,000 m³ of earth were hydraulically mined from the Bullion operation and deposited in the Quesnel River prior to 1905 (Holmes 2009). Fishery

Unknown to fisheries authorities at the time, a dam was constructed for mining operations at the outlet of Quesnel Lake, which allowed no fish passage from 1898-1899 (Holmes 2009). A rudimentary fishway was added in 1901; the dam was not dismantled till 1921. Meanwhile, owing to obstructions due to the Hell's Gate rock-slide perpetrated by railroad construction in the Fraser Canyon in 1913, few upper Fraser stocks, including Quesnel Sockeye, reached spawning grounds in that year. Over-fishing in the first half of the century exacerbated industrial impacts. Catches of Fraser Sockeye declined from 35 million fish in 1913 to less than 2 million per year across all cycle lines from 1915-1930 (Cass 1998). By 1941, the cumulative industrial impacts had decimated the dominant cycle line of the Quesnel stock: in that year, recorded Horsefly Sockeye escapement was 918 fish (Cone 1999).

Aided by fishway construction at Hell's Gate in 1945 and significant fishery conservation measures¹⁹, individual upper Fraser stocks began to recover. The Quesnel Sockeye run and the Horsefly River stock, in particular, recovered rapidly between 1941 and 2002 (Appendix E). The rebuilding Quesnel Sockeye escapement first exceeded 100,000 in 1953, 1,000,000 in 1985, and nearly 2 million in 2001 (Cone 1999; DFO 2014). Dominant-cycle Sockeye returns to the Quesnel system rose from < 1 million fish in the 1960s to 13 million by 1993 (Cass 1998).

The subdominant years have been slower to recover with the first significant escapement of 30,000 fish in 1982, then ranging from 140,000 to 1,000,000+ through the 1990s (Cone 1999), with peak escapement in 2002 (Appendix E). Escapement in the 1943-1991 off-cycle also increased through this period, from under 100 fish in the 1950's to over 40,000 by the 1990s (Houtman and Cone 2000).

Subsequent to the peak return years of the 1990s and early 2000s, there has been a rapid decline in dominant and sub-dominant cycles (Appendix E). Horsefly escapements have fallen below the long-term average since 2009, as Quesnel Sockeye survival has not reflected the improvements observed for most other Fraser Sockeye stocks since 2010 (DFO 2014). In addition, cyclic dominance apparently shifted from the 1901 line to the 1902 line as of 2010 (Appendix E). Currently, much uncertainty remains about the status of the QUESNEL-S Sockeye CU, which has been designated in the AMBER/RED ZONE by DFO (Grant et al. 2011).

officers first noted improvements in the Quesnel streambed below the mine in 1952: "Bullion Mine dump was widening out causing an easier passage for ascending salmon." (Manzon and Marshall 1980).

¹⁸ A catastrophic tailings pond embankment breach associated with the Mount Polley mine in Hazelton River released 25 million cubic metres of contaminated mine waste into Polley and Quesnel Lakes on August 4, 2014. Initial studies found elevated levels of copper concentrations in sediment samples and a sediment plume at depths below 30 m in the west arm of Quesnel Lake (Petticrew et al. 2015). The study also documented immediate but temporary increases in lake level rise of ~8 cm and benthic water temperature of up to 2.5°C. From September 8th - 15th, elevated turbidity in the upper Quesnel River in conjunction with a rapid decrease in river water temperatures was attributed to the arrival of the sediment plume at the lake outlet (ibid), potentially impacting migrant Sockeye during peak upstream migration (Figure 8, Figure 9).

¹⁹ Including phasing out of annual June/July log-drives down the Cariboo/Quesnel Rivers from 1963-1979 (Elvidge and Wickerson 1974; Manzon and Marshall 1980).

METHODS

DATA SOURCES AND ANALYSIS

Daily Sockeye Counts

Daily adult Sockeye migrant estimates were obtained from DFO personnel for two sites, based on two field methods:

1. From visual counts in the upper Quesnel River at Likely, B.C.; and
2. From acoustic counts in the upper Quesnel near the community of Likely, and in the upper Horsefly River, near its confluence with Quesnel Lake.

Estimates from visual counts were obtained at the Likely Bridge over the Quesnel River near the outlet of Quesnel Lake, for intermittent years between 1993 and 2001. Adult Sockeye migrants were enumerated visually by an observer stationed on the bridge between August and October. Sockeye tend to migrate along the bank in a single, relatively narrow column where they can be easily counted by an observer stationed above the shoreline. The counts were conducted to provide an index of relative abundance as migrants approached the spawning grounds during dominant and sub-dominant years (Cone 1999)²⁰.

Total daily estimates were expanded from 15-minute counts from a subset of hours between 09:00 and 16:00 hr. Counting effort varied throughout the migration period, with effort increasing as sockeye abundance increased. The number of 15-minute counts typically ranged from 4-8 per day, though during periods of low migration at the start and end of the run, estimates may have been based on as few as 4 counts per day. The daily sums from the counting effort at Likely Bridge were considered to have sufficient contrast and reliability to retain for analysis of return timing for six years between 1993 and 2001, omitting 1999 (Appendix B).

In 2005, a DIDSON²¹ acoustic imaging system was deployed to monitor adult migrants in Horsefly River to explore the utility of this technology to provide accurate, cost-effective and timely escapement estimation (Cronkite et al. 2006). The site selected for installation was approximately 900 m upstream from the river mouth where the Horsefly drains into Quesnel Lake. The unit operates by sampling 10-20 min each hour, 24 hr/day for the entire migration period. Total daily estimates (Appendix C) were based on manual counts of digital data that are expanded for time not sampled (Holmes, Cronkite and Enzenhofer 2004; Cronkite et al. 2006). With minor improvements, the DIDSON unit was used again in 2006, 2007, and 2010.

In 2009, a twinned DIDSON array was installed on opposite banks of the Quesnel River, near the QUESNEL RIVER RESEARCH STATION, two km downstream of the Likely

²⁰ High precision escapement estimation methods (mark-recapture and/or acoustic counts) were principally reserved for anticipated "high" escapement years (i.e. dominant or sub-dominant cycle lines), to reduce field program costs, which is why there are no daily migration estimates for many years. The expected escapement threshold for conducting high precision estimates was changed from 25,000 fish to 75,000 fish in 1995 due to ongoing funding pressures.

²¹ DIDSON - Dual-frequency Identification SONar imaging system.

Bridge visual count site (UFFCA 2010). Since the ensonified areas did not overlap at this installation, counts from 20-minute samples taken each hour from left and right banks were added together and then expanded for time not sampled. The DIDSON installation was operated also in 2010, 2014, and 2015 (Appendix C).

Ongoing issues with the Horsefly installation, such as accumulation of spawners in the ensonified zone, missed counts of fish spawning downstream of the installation, interference with tagging operations, plus the high costs of maintaining two high precision counter installations in large escapement years to enumerate migrants heading to Quesnel Lake tributaries, contributed to the decision to concentrate the acoustic count effort in the upper Quesnel River after 2010 (UFFCA 2010).

Though daily estimates based on counts at Likely Bridge were based only on a partial daily count and therefore are not directly comparable to DIDSON total daily estimates in absolute numbers, we assume that the *seasonal pattern* of daily abundances can be considered comparable between the two sources, when daily totals are standardized on the annual total count. To standardize the annual adult migration time-series for inter-site, inter-year and inter-stock comparisons, the percentage of total daily Sockeye counts (adult + jack) were calculated relative to the annual total stock count or adjusted escapement for each site, year and date.

The issue of the time lag (difference in count dates) between sites was relevant for analyses that incorporated all daily migrant data. For some analyses, the years of Horsefly count data were simply omitted. In other analyses, the Horsefly migration data were included with the Quesnel migration data after lagging (subtracting) a constant number of days from the Horsefly count date for each year to align with passage in the upper Quesnel. Little information is available regarding the fish travel time between upper Quesnel and lower Horsefly counter sites via the main arm of Quesnel Lake. The lag (in days) between sites utilized here was deduced based on several pieces of information, assuming equivalent inter-annual arrival timing for the sub-populations of the entire QUESNEL-S Conservation Unit.

- DFO field personnel recommended one to two days between sites.
- A comparison of the site-specific multi-year mean time-to-50% indicated a 2- to 5-day difference between Quesnel (Sep 2nd and 5th) and Horsefly (Sep 7th) counter sites (Figure 9, Figure 10).
- In 2010, DIDSON counters were installed in both upper Quesnel and lower Horsefly locations concurrently.
 - The first migrants arrived at the Horsefly site six days after the first migrants passed the Quesnel site (Appendix C). This provides one estimate of the time lag, assuming at least some of the first migrants at Quesnel were bound for Horsefly, and no sockeye were present in the Horsefly prior to DIDSON installation.

- Another estimate is provided by a subjective comparison of dates of migratory peaks at the two sites in 2010 (Appendix D), which suggest 4-6 day differences near the beginning of the run (late August), 3-4 days near the middle (5-Sep), and perhaps as little as 1 day late in the run (12-Sep).
- A non-parametric covariation analysis (described below, p. 22) indicated a 5-day difference between Quesnel and Horsefly counter locations.

Annual plots of daily and cumulative migration rate (i.e. percent relative to the annual total escapement) were overlaid with historical mean and maximum daily migration rate by Julian day-of-year, for inter-annual migration pattern comparisons. Daily migration rate data (%) were further transformed using the arcsin function to normalize the percentage data where appropriate for parametric analyses (Sokal and Rohlf 1969).

Univariate statistical analyses were used to characterize the multi-year stock migration data including: number of observations, central tendency (mean, median, mode, etc.), scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis). Median (50th percentile) and 75th percentile values of the historical datasets were calculated to establish categories of "insignificant" (negligible) daily migration rates (0-50th percentile), versus "significant-but-moderate" (50-75th percentile) and "significant-and-high" (75-100th percentile) migration activity.

Spawn Timing

Annual Sockeye spawn timing data in the Horsefly River were obtained as a supplemental indicator of environmental impacts on migration timing for a majority of years between 1940-1995 (Houtman and Cone 2000) and 1996-2015 (DFO Fraser Stock Assessment; Appendix F).²² These timing indices consist of an annual "Arrival" date and one or more "Peak Spawn" dates, based on field observations by DFO personnel during spawning ground surveys.

Dates were converted to Julian day-of-year for inter-annual comparisons. Where multiple dates or date ranges were provided for a given year and index, the first date in the range was used to define the Arrival Date, and the median date was used to define the Peak Spawning Date. Where multiple distinct spawning peak dates were observed, median dates for both were retained.

Univariate statistical analysis was applied to Julian dates to estimate median (P50), P10, and P90 timing for the two timing indices – Arrival Time and Peak Spawn Time – to assess trends. The timing indices were correlated using parametric least-squares regression to explore the relationship between annual arrival and peak spawning time. Further analyses were focused on the dominant and sub-dominant cycle lines^{23 24}; dates for off-cycle lines were retained for review but not deemed

²² Not all years were surveyed due to lack of funding for field operations in non-dominant cycle years.

²³ Dominant cycle line: 1953...2005, 2010...2014.

²⁴ Sub-dominant cycle line: 1954...2006, 2009...2013.

suitable for inter-annual comparisons due to confounding factors associated with differences in field observation efforts.²⁵ To assess environmental influences, timing indices for the combined dominant and sub-dominant cycle lines were cross-correlated with estimated daily mean water temperature indices (reconstructed for the lower Quesnel River and the lower Horsefly River), and flow indices (lower Quesnel River hydrometric site 08KH006, and upper Horsefly River hydrometric site 08KH010), described below.

Environmental Data

Meteorological, hydrographic, and water temperature data necessary for derivation of long-term (30+ years) time-series of water temperature and flow conditions were assembled from online databases, published documents, unpublished reports and data from government agencies (e.g. ENVIRONMENT CANADA, WATER SURVEY OF CANADA (WSC), ENVIRONMENTAL WATCH PROGRAM, FISHERIES AND OCEANS CANADA (DFO)).

Basic statistical analyses were used to document and describe the available data, establish relationships between regional air and site-specific water temperature datasets, and define inter-site relations for both water temperature and discharge to infill missing observations. STATISTICAL ANALYSIS SOFTWARE (SAS[®] Version 9.3) was used to assemble and analyze data from MICROSOFT EXCEL[®] spreadsheets. The resulting datasets were stored in a relational FRESHWATER ENVIRONMENTAL VARIABLES DATABASE (Hyatt and Stiff, DFO; unpublished data) and are available from DFO upon request.²⁶

Hydrology

The WATER SURVEY OF CANADA (WSC, ENVIRONMENT CANADA)²⁷ maintains active hydrometric gauging stations at multiple locations in the Quesnel/Horsefly watersheds (Figure 7). Meta-data for select stations, including elevation and mean annual discharge (MAD), are available in Table 2. Mean daily discharge data were obtained from the web archives²⁸ for the following stations:

²⁵ Geographical coordinates and related meta-data for annual spawning ground surveys were either not historically specified, or captured in stored datasets. Large differences in annual fish abundance likely played a role in where spawning activity occurred within the 63-km of spawning habitat in the Horsefly River and its tributaries. At low run sizes (pre-1980s, and all off-cycle years), the relatively low numbers of spawners may have been typically concentrated in certain reaches of the Horsefly, appearing to arrive and/or spawn at different times simply by virtue of the differences in distance travelled or observation effort. Furthermore, during off-cycle years, minimal field effort was directed towards spawning ground surveys, calling into question the accuracy of timing data in those years.

²⁶ Contact Howard.Stiff@dfo-mpo.gc.ca or Kim.Hyatt@dfo-mpo.gc.ca for information on the MICROSOFT ACCESS[®] database.

²⁷ ENVIRONMENT CANADA – WATER SURVEY OF CANADA website: <http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=894E91BE-1>.

²⁸ Data up to 2012 were available from the ECCC WSC archives; preliminary data from 2013-2015 were provided by Lynn Campo (ECCC) [Aug 2016].

- QUESNEL RIVER AT LIKELY (1924-2015; WSC station 08KH001; elevation ~730 m) is located in the upper Quesnel River at the outlet of Quesnel Lake (drainage area: 5,970 km²). This station is located above the Quesnel/Cariboo confluence (Quesnel Forks) and therefore does not incorporate the significant freshwater inputs from the Cariboo watershed (WSC station 08KH003; drainage area: 3,260 km²). Data extend almost continuously from 1924 to 2015 for the migratory period (Aug-Sep), except for missing flows in 1937.
- QUESNEL RIVER NEAR QUESNEL (1939-2015; WSC station 08KH006; elevation ~470 m) is located in the lower Quesnel River, about 38 km upstream of the Fraser/Quesnel confluence at the city of Quesnel. The time-series extends continuously from 1939-present with no missing dates during the migratory period. Capturing the drainage for the entire 11,500 km² of the Quesnel watershed (MAD: 241 cms), the hydrometrics at this site likely represent the general locus of maximum energy expenditure by upstream migrants.
- HORSEFLY RIVER ABOVE QUESNEL LAKE (2004-2015; WSC station 08KH031; elevation ~770 m; drainage: 2,300 km²). This abbreviated time-series is located in the lower Horsefly River, ~8 km above the drainage into Quesnel Lake, and therefore integrates potential flow impacts on spawners moving into the Horsefly system. MAD is about 36 cms, with mean summer flows of ~16 cms. 142 records in 2004, 2008 and 2011 were missing (out of a total of 802 Aug-Sep dates).
- HORSEFLY RIVER ABOVE MCKINLEY CREEK (1955-2015; WSC station 08KH010; elevation ~820 m; drainage: 790 km²) is located in the upper Horsefly River and provided a more extensive time-series, with continuous data between 1955-1957 and 1965-2015, useful for extending or in-filling lower Horsefly flows via statistical relations. MAD is about 20 cms, providing the majority input to lower Horsefly flows. MCKINLEY CREEK (08KH020), MOFFAT CREEK (08KH019), and LITTLE HORSEFLY RIVER (08KH008) each added low inputs (MAD < 5 cms); only the first two sites provided sufficient summer flow data to incorporate into statistical relations with lower Horsefly data.

Simple least-squares regression models (linear: $Y = a + bX$; loglinear: $\text{Log}Y = \text{Log}a + b * \text{Log}X$) were derived for estimating missing or historical daily QUESNEL RIVER NEAR QUESNEL discharge as a function of the more extensive time-series for QUESNEL RIVER AT LIKELY. Model calibration was based on July-Aug-Sep data (to capture observations at peak mid-summer flows) subsetted for every 10th observation, to reduce the influence of autocorrelation effects. Model selection was based on highest correlation and lowest root mean square error or adjusted AKAIKE INFORMATION CRITERION (AICc).

Similar predictive relations for flows at QUESNEL RIVER NEAR QUESNEL were established with CARIBOO RIVER BELOW KANGAROO CREEK, and for multiple regressions including both up-river sites. Stepwise regression was used for final selection of the up-river sites for inclusion in the multi-variate predictive model. Infilling or extension of the QUESNEL RIVER NEAR QUESNEL site time-series from the three resulting predictive models was based on highest explained variance and the

availability of predictor data for a given date. Goodness-of-fit was assessed using correlation of observed versus predicted QUESNEL RIVER NEAR QUESNEL data and subjective examination of time-series plots.

A similar process was used to infill and extend the flow time-series for the lower Horsefly. Data for HORSEFLY RIVER ABOVE QUESNEL LAKE were regressed against HORSEFLY RIVER ABOVE MCKINLEY CREEK, MCKINLEY CREEK, and MOFFAT CREEK predictor data individually and via stepwise multi-variate regression.

Univariate statistical analyses were used to characterize station discharge data, based on number of observations, central tendency (mean, median, mode, etc.), scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis). Deciles and quartiles were derived for the migration months (August-September) to identify drought (< 10th percentile), moderate (10-90th percentile) and flood (95-100th percentile) categories, plus low and high thresholds relevant to migration activity. Plots of the historic mean and variance of daily discharge were used to characterize the flow patterns during the adult Sockeye migration period (August-September).

Water Temperature

Water temperature data were principally supplied courtesy of DFO ENVIRONMENTAL WATCH PROGRAM (EWP) which maintains a water temperature database for a network of real-time and archival data-logger stations at key locations in the Fraser Basin (Figure 7) for salmonid research and management purposes (Hague, Patterson and MacDonald 2008)²⁹. Quality-controlled daily mean water temperatures based on either daily minimum and maximum values (pre-2000), or hourly readings (2000-present; see Hague et al. 2008 for methods), were extracted from the FRESHWATER WATER TEMPERATURE DATABASE³⁰ (Thompson et al. 2010) for the following years³¹:

- Lower QUESNEL RIVER (site QR-1) – 2000-2012 – located approximately 1 km upstream of the city of Quesnel.
- Lower HORSEFLY RIVER (site HR-22) – 1995-2010, 2012. Approximately 22 km upstream of Quesnel Lake.
- Lower Quesnel River water temperature data were supplemented with daily mean water temperatures for 2006-2015 derived from hourly datalogger readings at an active real-time ECCC WSC station 08KH006 (QUESNEL RIVER NEAR QUESNEL), located approximately 37 km upstream of QR-1.³²
- FRASER RIVER AT QUALARK (site FR-190) – 1941-2011 – located near Yale,

²⁹ DFO ENVIRONMENTAL WATCH PROGRAM: <http://www.pac.dfo-mpo.gc.ca/science/habitat/frw-rfo/index-eng.html>

³⁰ Temperature collection methods and site descriptions for network locations are detailed elsewhere (Barnes and Magnusson 2000; Brown et al. 1998; Barnes and Walther 1997; Lauzier et al. 1995).

³¹ Water temperature data were made available by David Patterson, DFO EWP, 2012.

³² WSC temperature data were provided courtesy of Lynn Campo, ECCC [Aug 2016]

B.C., about 20 km north of Hope, B.C., and approximately 350 km downstream of the Fraser/Quesnel confluence. Data were reconstructed from hourly datalogger data (1996-2006) as documented in Patterson et al. (2007).

Water temperature data cleanup consisted of examining descriptive statistics and graphic output to identify anomalous data and outliers, in conjunction with a review of field notes regarding datalogger installation and removal dates and times. Anomalous data were corrected, or retained in the database but flagged for omission (i.e. OMIT field = YES) from data analyses.

Univariate statistical analyses were used to characterize the daily mean water temperature (MWT) time-series for the period of record, i.e. number of observations, central tendency (mean, median, mode, etc.), scale (range, variance, extreme values and outliers), and shape (skewness, kurtosis).

LOWER QUESNEL RIVER (REFERENCE SITE)

Quesnel River water temperature datasets from EWP QR-1 and WSC 08KH006 sites were aligned by date and cross-correlated for statistical assessment. Analysis of means, variance, and pairwise t-tests were used to determine whether these data could be considered drawn from the same population.

To extend the water temperature time-series at the reference location in the lower Quesnel River, linear, log-linear, and log-log regression relations were assessed to derive water temperature transfer functions between QUESNEL RIVER AT QR-1 as a function of water temperature at QUESNEL RIVER at WSC station 08KH006 based on all available data for the overlapping years (2006-2012). The most parsimonious model was selected based on maximized R-squares and goodness of fit, and used to reconstruct missing daily mean water temperatures for the QR-1 reference site, and extend the water temperature time-series through 2015. This reference site dataset was then used in air/water temperature relations – described below – to develop a site water temperature dataset suitable for retrospective and future climate modelling studies.

HORSEFLY RIVER

Water temperature data obtained at site HR-22 were used in air/water temperature relations – described below – to develop a Horsefly River water temperature dataset suitable for retrospective and future climate modelling.

FRASER RIVER AT QUALARK

Water temperature data were obtained for site FR-190 to establish simple same-day water temperature relations with Quesnel River and Horsefly River.

Air Temperature

Studies have demonstrated that variations in regional air temperature (which often span the 19th century) are generally sufficient to explain as much as 80% of the variation in local daily mean water temperature (Mohseni and Stefan 1999; Hyatt and Stockwell 2003; Pilgrim, Fang and Stefan 1998; Stefan and Preud'homme 1993; Webb and Nobilis 1997). Linear and nonlinear regression models are known to be

useful at moderate air temperatures typical of adult Sockeye migration periods (i.e. 10-20°C), while water temperature "extremes" (<5°C or >20°C) are more appropriately modeled nonlinearly (Mohseni, Stefan, and Erickson 1998). The resulting time-series spanning the period of record of meteorological observations can be used as a consistent index of local water temperature conditions at the daily time-scale, and summarized to examine trends and shifts in water temperature regimes at longer time-scales (e.g. decadal).

ENVIRONMENT CANADA'S METEOROLOGICAL SERVICES group maintains an archive of climate, hydrographic and water quality data gathered from both active and inactive stations distributed throughout British Columbia and the Yukon.³³ For the majority of Canadian climate stations, air temperature measurements are taken from self-registering, maximum and minimum thermometers that record parameter extremes over a 24-hour period. Daily mean temperature is defined as the average of the maximum and the minimum temperatures attained during the 24-hour period. These datasets undergo detailed quality-control analysis before posting to the web site.

In addition, ENVIRONMENT CANADA has refined air temperature and precipitation time-series for certain stations as part of the ADJUSTED AND HOMOGENIZED CANADIAN CLIMATE DATA (AHCCD) group of climatological stations across Canada. These data incorporate adjustments applied to the original station data to address non-climatological shifts related to changes in instrumentation and observation conditions or procedures, thus optimizing their use for climate research (Vincent et al. 2012). Sometimes the observations from several stations were joined to generate a long time series.^{34 35}

The EC web site was accessed to identify potential sites of air temperature data within the area of interest for statistical relationships with water temperature data (Figure 1). EC AHCCD climate station QUESNEL (1096630; 53.03°N x 122.52°W; elev. 545 m) was selected for climate data retrieval for Quesnel watershed sites on the basis of:

- (i) the quantity and quality of data available (1900-present);
- (ii) proximity to hydrometric and water temperature sites (<10 km to the lower Quesnel River sites; ~100 km to lower Horsefly River sites); and
- (iii) the potential to routinely update the time-series from an "active" climate station.

Minor gaps in the daily air temperature record at QUESNEL during the Sockeye migration period were found in 2006, 2010-2015, which were estimated from linear

³³ ENVIRONMENT CANADA Climate Data: http://climate.weatheroffice.gc.ca/climateData/canada_e.html

³⁴ ADJUSTED AND HOMOGENIZED CANADIAN CLIMATE DATA (AHCCD) – Daily AHCCD air temperature data may be obtained by request to AHCCD@ec.gc.ca. See the [ENVIRONMENT CANADA](http://climate.weatheroffice.gc.ca/) website for monthly AHCCD values.

³⁵ AHCCD Licence Agreement: *This work contains data licenced "as is" under the Government of Canada Open Data Licence Agreement. Such licencing does not constitute an endorsement by the Government of Canada of this product.*

relations with nearby AHCCD EC station WILLIAMS LAKE – approximately 120 km south of Quesnel.³⁶ The resulting observed + estimated air temperature dataset is referred to here at the QUESNEL STANDARD air temperature.

Multi-day Mean Air Temperature Index

The best predictive air-to-water relationships exist for associations between daily mean water and multi-day mean air temperature (Hyatt and Stockwell 2003; Webb and Nobilis 1997). Centered moving averages (i.e. mean temperatures from $Date - (n-1)/2$ to $Date + (n-1)/2$, where n is the number of days) center the multi-day means such that peaks and troughs more accurately align with the flux in the original daily MAT time-series (Hyatt et al. 2015).

For each EC meteorological dataset, correlation analysis was used to identify the multi-day moving average air temperature index with the lowest n -value (for $n = 1, 3, 5, 7, 10$ days)³⁷ while retaining a high Pearson correlation coefficient with a representative subset of data from the associated daily mean water temperature site. The multi-day CMAT index with the lowest adjusted AKAIKE INFORMATION CRITERION (AICc) and the highest Pearson correlation coefficient for the calibration data was used for subsequent air/water temperature regression relations.³⁸

Air/Water Temperature Relationships

Hyatt et al. (2015) describe the basic methodology used to estimate missing or historical daily MWTs based on statistical relations with the regional 7-day CMAT index. The authors calibrated linear (Equation 1) and logistic (Equation 2) air-to-water temperature relations using a subset of the site daily MWTs as a function of the regional multi-day air temperature indices (QUESNEL STANDARD):

Equation 1: $T_w = \alpha + \beta * T_a$; where

T_w is the *estimated mean water temperature*;

T_a is the *multi-day mean air temperature index*;

α is the y-intercept and β is the regression coefficient.

Equation 2: $T_w = \mu + (\alpha - \mu) / (1 + e^{-(\beta - T_a)})$; where

T_w is the *estimated mean water temperature*;

T_a is the *multi-day mean air temperature index*;

α is the *estimated maximum water temperature*;

μ is the *estimated minimum water temperature*;

³⁶ QUESNEL Daily Mean Air Temp = $0.863 + 2.92 * \text{WILLIAMS LAKE Daily Mean Air Temp}$; $r = 0.92$; SE = 0.006; $P = 0.0001$; $n = 3,424$ (summer months July-Aug-Sep only).

³⁷ $n = 1$ corresponds to the "observed" mean daily air temperature time-series.

³⁸ Although the 10-d CMAT index was included in this assessment, and (usually) generated the maximum correlation, this index was ultimately discarded due to the undesired trade-off between high correlation versus the damping effect on daily air temperature variation and resulting daily water temperature estimates (Hyatt et al. 2015).

γ is a measure of the steepest slope of the function;

β represents the air temperature at the inflection point.

The existence of hysteresis³⁹ in a water body, and the resulting need to use separate warming and cooling season regression models to describe air/water temperature relations at a particular site, was evaluated for both linear and logistic models.

In the linear approach, an additional categorical "season" predictor was a significant effect (signifying different seasonal model intercepts), and/or whether there was a significant interaction effect with air temperature, indicating significant differences in seasonal model slopes (i.e. $P < 0.05$ for the Type III model sum of squares (SAS 1987).

For the logistic analysis, hysteresis was assessed by comparison of the *Nash-Sutcliffe Coefficient* (NSC) value for the all-season model versus the averaged NSC values for the separate warming and cooling season models (Mohseni et al. 1998):

Equation 3: $Hysteresis = [(NSC_w + NSC_c) / 2 - NSC_{all}] \geq 0.01$; where

NSC_w = NSC for warming season;

NSC_c = NSC for cooling season;

NSC_{all} = NSC for all seasons combined.

Water Temperature Time-Series Reconstruction

MODEL CALIBRATION

Linear and logistic regression relations described above were developed using site-specific daily mean water temperature (MWT) as a function of the regional air temperature index (7-day centered QUESNEL MAT variate) for two locations in the watershed: (lower) HORSEFLY RIVER (near the spawning grounds), and (lower) QUESNEL RIVER (NEAR QUESNEL).

Selection of data for the calibration dataset was not randomly determined, but based on subjective and statistical examinations of individual annual air and water temperature time-series plots and correlations. A minimum of 5 years of temperature data across multiple decades and including sufficient observations at the upper end of the range for both warming and cooling seasons is generally necessary to define a truly representative air/water temperature relationship.

Years with consistent and apparently unbiased water temperature observations associated with a maximum range of temperature values for both warming and

³⁹ Hysteresis: the heat storage properties of water. Hysteresis is a measure of the seasonal effect of the differential rates of heat exchange between air and water as the spring-to-summer period warms up and the fall-to-winter period cools down (Wetzel 1975). The observed pattern of hysteresis is related to the complex physics of air-water heat exchange processes. These involve evaporative cooling of the lake in the late summer-to-fall, thermal de-stratification in the fall-to-winter; rapid, wind-induced, mixing of surface and deep waters through the winter, and initiation of thermal stratification and evaporative cooling once again in the spring-to-summer season.

cooling periods⁴⁰ were preferred for characterizing the all-year air/water temperature relationship. Years of evident bias or excessive anomalies in the water temperature observations were not evident in EWP's FRESHWATER WATER TEMPERATURE DATABASE, but some incomplete years were excluded from the calibration dataset (e.g. 2002 – missing data July 15-27). Data years not used for model calibration were used for validation of statistical relations.

To determine whether seasonally-distinct regression relations were required, the air/water temperature data for each site were checked for hysteresis. To detect hysteresis, separate functions were fitted to the air and water temperature data in each of the warming and cooling seasons.

The warming and cooling seasons were first distinguished from each other by determining the seasonal temperature "turn-around point" (the timing of the winter season turn-around point was not required for the purpose of this analysis).⁴¹ The seasonal transition dates were obtained by plotting weekly mean daily water temperatures as a function of weekly mean daily air temperatures, and connecting the points chronologically. The week associated with the maximum mean air temperature, indicating the ending of the warming season (and the starting point of the cooling season) was converted to day-of-year to pinpoint the seasonal turn-around date.

Site-specific hysteresis effects were then assessed as described above using all-year all-season data for both linear and logistic models. If hysteresis was detected in either case, linear and logistic models were then fitted to the all-year data for each of the warming and cooling seasons separately.

MODEL VALIDATION

Site-specific linear and nonlinear air/water regression parameter estimates were tested for statistical significance, and applied to the air temperature indices to estimate reference site daily MWT for the period of record of air temperature data. Modeled MWTs for the validation dataset were correlated with observed reference site water temperature data graphically and statistically as a measure of goodness-of-fit. The all-year Pearson and Spearman correlations for the validation years were compared between model types to determine whether linear or logistic outputs best simulated observed MWTs at the Quesnel and Horsefly River reference sites.

Precipitation

Precipitation data may be correlated with discharge levels and water temperature. They may also be useful for downscaling projected changes in regional precipitation from global or regional climate models to specific sites at the local level.

⁴⁰ Derivation of the seasonal flux point between warming and cooling "seasons" is described below.

⁴¹ For linear models, an additional "winter" season was defined (November 25th to March 10th), encompassing the cold-weather months when changes in air temperature are not reflected in changes in water temperature due to hysteresis effects at low temperature extremes. These data were omitted from this analysis.

Daily precipitation records for the Quesnel watershed were obtained for QUESNEL AHCCD (station 1096630; 53.0°N x 122.50°W; elev. 545 m) for 1900-2006 from Environment Canada.⁴² Non-AHCCD precipitation data from EC station QUESNEL AWOS (station 1096625; 53.0°N x 122.50°W; elev. 545 m) for 2007-2015 were appended. Due to the highly localized and non-normal distribution of precipitation data, missing values were not interpolated or estimated based on parametric statistical relations with other stations.⁴³

Trend and Exceedance Analyses

AIR TEMPERATURE

Historic regional air temperature data (based on QUESNEL STANDARD daily MAT, 1900-2015) were summarized by year to obtain the mean value during the summer months (August-September), and plotted to review the long-term time trend in regional air temperature conditions during the migratory period. Non-parametric test statistics were calculated for these months over the 116-year period (1900-2015) for detection of trends (Spearman's rho and Mann-Kendall statistics), and step changes in the mean (rank sum) (TREND 1.0.2 software: Kundzewicz and Robson 2000). Regime shift detection using sequential t-test analysis (STARS 6.2 software) was applied to mean Aug-Sep air temperature after prewhitening using a Target P = 0.05, Year Cutoff Length = 20, Tuning Constant = 2 and a Subsample size = 12 (Rodionov 2004).

Mean monthly air temperatures of 20°C are considered an upper threshold for salmonid life history stages (Mote et al. 2003). Historic mean daily QUESNEL STANDARD air temperature data were analyzed for the frequency of dates in each year and month (August-September) for which mean daily air temperature exceeded this threshold value, and summarized by decade as a trend indicator. In addition, the frequency of annual periods in which water temperature continuously exceeded this value, and the mean duration (days) of these periods, was derived for each year, and summarized by decade to review trends in the frequency and duration of continuous periods of potentially stressful weather conditions.

WATER TEMPERATURE

Reconstructed daily mean water temperature (MWT) data were summarized by site and year (1900-2015) in the lower Quesnel (at site QR-1) and lower Horsefly (at HR-22) to determine mean values during the summer months (August-September), and plotted to review the long-term time trend in site-specific water temperature conditions during the migratory period.

A threshold exceedance analysis, tallying the decadal mean monthly frequency of

⁴² ADJUSTED AND HOMOGENIZED CANADIAN CLIMATE DATA (AHCCD) – Daily AHCCD precipitation data may be obtained by request to AHCCD@ec.gc.ca. See the [ENVIRONMENT CANADA](http://www.environment.ca) website for monthly AHCCD values.

⁴³ An alternative approach, not attempted here, may be to obtain daily precipitation data for multiple regional meteorological stations to derive an appropriate area average. Source: [NATIONAL CLIMATE DATA AND INFORMATION ARCHIVE](http://www.nationalclimatearchive.ca) (March 2013).

dates for which the reconstructed MWT temperature index exceeded 18°C ($\text{POT}_{18^{\circ}\text{C}}$; i.e. peak-over-threshold $> 18^{\circ}\text{C}$), was used to examine site-specific trends in water temperature conditions during the adult migration period (August-September).⁴⁴ Since Aug-Sep observed water temperatures in Horsefly River generally exceed those in the Quesnel River, the lower Horsefly site was deemed the critical location for analysis of water temperature impacts.

In addition, the frequency of annual periods in which water temperature continuously exceeded this value, and the mean duration (days) of these periods, was derived for each year. These data were summarized by decade to review trends in the frequency and duration of continuous periods of potentially stressful water temperature conditions.

RIVER LEVEL / DISCHARGE

Linear and non-parametric test statistics were applied to the extended (observed plus estimated) discharge time-series associated with the lower Quesnel and lower Horsefly locations for detection of trends (Spearman's rho and Mann-Kendall statistics), and step changes in the mean (rank sum) (TREND 1.0.2 software: Kundzewicz and Robson 2000). Regime shift detection using sequential t-test analysis (STARS 6.2 software) was applied to mean Aug-Sep air temperature after prewhitening using a Target $P = 0.05$, Year Cutoff Length = 20, Tuning Constant = 2 and a Subsample size = 12 (Rodionov 2004).

For exceedance analyses, both "low flow" and "high flow" dates are of potential interest, since, conceivably, either flow extreme may negatively impact upstream migration. Preliminary review of discharge data suggested that high flows might be an issue in the lower Quesnel, where watershed discharge volumes are largest. Documented rapids exist in Quesnel Canyon that may result in high water velocity barriers either at Big Canyon (14 km from the mouth of the river), or Little Canyon (17 km further upstream) (Figure 2, Figure 6).

For high flow exceedance analyses, source data from observed lower QUESNEL RIVER discharge data were utilized (1939-2015), extended by statistical relations with upstream WSC sites⁴⁵, to obtain the longest discharge time-series via predictive regression. The frequency of dates for which observed water levels were greater than the upper 90th percentile (~ 375 cms) was calculated by year and month (August-September), and summarized by decade. From these data, the frequency of annual periods in which flow levels continuously remained below/above the lower/upper thresholds, and the mean duration (days) of these periods was derived for each year, and summarized by decade to review trends in the frequency and duration of continuous periods of potential flow barriers to upstream migration.

The lower Horsefly River was deemed the most likely location for "low flow" events potentially affecting migrants approaching the spawning grounds. The time-series for

⁴⁴ Insufficient data exist to contrast inter-annual results at higher temperature thresholds (i.e. $> 18^{\circ}\text{C}$).

⁴⁵ Extending the lower Quesnel discharge time-series statistically from upper Quesnel (at Likely) and/or Cariboo River added 1924-1938 to the analysis.

HORSEFLY RIVER ABOVE QUESNEL LAKE was infilled and extended back to 1964 based on statistical relations with its tributaries. The frequency of dates for which observed/estimated water levels in the lower Horsefly were less than the lower 10th percentile (~8 cms) was calculated by year and month (August-September), and summarized by decade.

Migration, Temperature and Discharge

Daily mean water temperature and discharge estimates were merged with daily Sockeye migration rate data to test the null hypothesis that daily Quesnel Sockeye migration rates were not associated with changes in water temperature and discharge.

To that end we attempted to detect whether temperature and discharge levels were significantly associated with differences in daily migration rate (with and without lagged daily migration data from the Horsefly counter site), and identify where that might occur over the length of the Quesnel/Horsefly system, from the immediate vicinity of the Quesnel⁴⁶ and Horsefly counter sites, to the confluence with the Fraser River. For statistical analysis at the Horsefly site, only the four years of daily migration data from the Horsefly DIDSON were applicable. For analysis at the Quesnel site, statistical tests were assessed with: Likely Bridge count data only (six years); Quesnel DIDSON count data only (four years); both Likely Bridge and Quesnel DIDSON data (ten years); and all Quesnel data plus Horsefly count data time-lagged five days earlier (based on deductions in Daily Sockeye Counts section above) to align with Quesnel site passage (13 years).

The existence of a potential velocity barrier in Quesnel Canyon pointed to the lower Quesnel as an analytical starting point (applying appropriate time lags for migrant data), using environmental estimates associated with the lower QUESNEL RIVER NEAR QUESNEL reference site as the independent variables. Since no data exist regarding Sockeye migrant swim speed within the Quesnel watershed, estimates of the lag time (in days) to align daily migration data obtained in the upper Quesnel River with lower Quesnel environmental conditions were largely inferred from studies of other Summer stocks' swim speed (Killick 1955, p. 93; Idler and Clemens 1959, Table 1; Hague et al. 2008). Applying the lower end of the observed range (32-52 km/d) in Summer Sockeye swim speeds in the Fraser River – due to the increased energetic requirements of the steeper ascent in the Quesnel River – Sockeye might take a minimum of 2-3 days to ascend the 100-km Quesnel River. Tag studies in 1944 and 1945 found Sockeye averaged 13.8 km/d ascending the smaller Chilcotin/Chilko system (IPSFC 1946). At that speed, Sockeye would take a maximum of 7 days to swim up Quesnel River. Given the elevation change along the river, plus the annual variability in Quesnel River flows and fish condition and numbers after exposure to heat and flow challenges in the lower Fraser and Hells Gate, a wide range of travel times (2-7 days) was deemed reasonable to align Sockeye migration data with lower Quesnel River conditions.

⁴⁶ Due to the proximity of the DIDSON counter site ~2 km downstream of the Likely Bridge counter site, these two sites were considered to be at the same location with respect to Sockeye travel time.

To address some of the statistical limitations associated with skewed and/or truncated data distributions (i.e. in migration rate and discharge), non-parametric categorical methods were utilized, based on the COCHRAN-MANTEL-HAENSZEL test statistic of GENERAL ASSOCIATION (CMH-GA; SAS 1987). The CMH-GA statistic provides a stratified test of association between a response variable – migration rate (daily % of annual total migrants) – versus multiple environmental variables after controlling for stratum level in the environmental factors.⁴⁷

For the multi-way contingency tables, the continuous variates were classified according to thresholds based on percentiles (i.e. for migration and discharge) or assumed upper limits (for water temperature). For migration rate data, the 50th percentile was used as a threshold to exclude dates of 'negligible' migration (<50th percentile) in the tails of the run timing, while the 75th percentile was used as the threshold to define whether a daily migration rate value was a negative anomaly ("low" migration) versus a positive anomaly ("high" migration).

To attempt to infer the "statistically-optimum lag time" (days) for which migration rates were most associated with river conditions – the CMH-GA analysis was repeated at each integer temperature threshold (13-18°C) and flow decile (250-400 cms in the lower Quesnel; 6-30 cms in the lower Horsefly), for migration data merged with time-lags of 0 days (corresponding to environmental effects occurring at the counter sites) to 10 days (corresponding to downstream effects acting on migrants). A heat map of the resulting CMH GENERAL ASSOCIATION statistics was used to identify the date lag, discharge, and temperature threshold combinations that generated local maxima of significant association with categorical changes in migration rate. The pattern was used to help identify the most likely time lag and, by extension, the potential location of the corresponding environmental influence contributing to variation in daily migration rates at the counter sites.

For migration rate data, the 75th percentile (P75) was used as the threshold to define whether a daily migration rate value was a negative versus positive anomaly, and the 95th percentile of migration rates was used to define whether a positive migration rate was "moderate" (i.e. 75th - 95th percentile) or "high" ($\geq$ 95th percentile).

For discharge, the 75th percentile (~350 cms) of daily flow levels in the lower Quesnel River during the Sockeye migratory period were used as a starting point to classify "low" (negative) versus "high" (positive) flow events.

High discharges were examined for Horsefly River, but at P90 flows of ~30-40 cms (one-tenth of Quesnel P75 levels), were not considered an issue for migration – especially in the absence of known obstructions to fish passage in the lower Horsefly. Low flows, however, were considered analytically, using the P10 threshold of 8 cms.

Observed water temperature values near the upper tolerances of Sockeye Salmon were infrequent; thus the maximum Quesnel temperature threshold available for

⁴⁷ The stratified analysis provides a way to adjust for the possible confounding effects of water temperature and discharge without being forced to estimate parameters for them (SAS 1987).

statistical testing was at the lower end of known thermal impact levels, i.e. 18°C (Hyatt et al. 2015)⁴⁸. This corresponded approximately to the P90 of water temperatures in both Quesnel and Horsefly Rivers.

An unweighted frequency distribution of observed migration dates (i.e. filtered for non-zero migration rates) at varying levels of temperature and discharge was then generated for the selected lag, to indicate the general distribution of temperature and flow conditions that were encountered by fish during the migratory period.

A similar frequency distribution of active migration dates, *weighted by the daily migration rate*, was then used to quantify *how much* migration occurred at a given temperature and discharge level. In contrast to the simple distribution of dates of migration (which leave *amount* of fish out of the equation), these plots displayed the water temperature and flow conditions associated with highest migration rates (presumably most favourable to salmon migration), and, by extension, possible thermal and hydrological limits (if any) that differentiate high versus low rates of migration.

Environmental thresholds derived subjectively from the above analyses were used to calculate daily deviations in the modeled water temperature and discharge time-series. These were combined with deviations in daily migration rate (from the median of the historical daily migration rate) on annual anomaly plots to examine the pattern of daily variation in each time-series in relation to each other.

RESULTS

SOCKEYE MIGRATION DATA

Limited daily migrant count data were available for the Quesnel system, specifically: six years of visual counts and four years of acoustic counts in Quesnel River, and four years of acoustic counts from Horsefly River. Seven of the eight years of acoustic counts were unique (2010 overlapped both sites), for a total of 13 unique years between 1993 and 2015 (Table 3 - Table 4).

Based on these data, adult migrant fish counts at all counter sites typically commenced in early-to-mid August, and terminated by mid-October. Time-to-50% (TT50%) occurred approximately September 2nd (Figure 8; Likely Bridge) to September 5th (Figure 9; DIDSON site) in the upper Quesnel. In the lower Horsefly, TT50% occurred a couple days later, around September 7th (Figure 10; DIDSON site).

Annual total counts reflected the wide variability in Sockeye returns across cycle

⁴⁸ However, the fact that Quesnel Sockeye migrants must previously experience temperatures 2-3°C higher as they ascend the Fraser River suggested that a Quesnel/Horsefly temperature threshold of 17-18°C might serve as a local indicator or proxy for Fraser temperature levels known to affect Sockeye migration rates and patterns. Thus, a local temperature threshold of 18°C – akin to 19-20°C downstream in the Fraser – was used as a starting point to classify lower Quesnel/Horsefly River daily mean temperature data as “low” (negative) or “high” (positive). Of course any significant ‘temperature effects’ apparent in the analysis would necessarily be geographically distant – that is, co-variation associated with conditions further downstream in the Fraser.

lines for this stock. The dominant cycle line was in evidence between 1993 and 2001 in the visual counts, and again in 2005 according to acoustic estimates (645,210 fish counted at Horsefly), but may have failed in 2009 when only 157,541 fish were estimated at the Quesnel counter. The sub-dominant 2010 year then led to a strong 2014 spawning escapement (824,309 at Quesnel), with an apparent shift in the dominant cycle by one year as of 2009/2010 (Table 4).

Given the paucity of daily escapement data and strong cyclic inter-annual variation, multi-year summarization of counter data has little meaning. From the expanded acoustic counts, it appears that total annual escapement ranged from a low of 43,000 fish in 2015 to over 824,000 fish in 2014. During dominant cycle lines (2005, 2014), Horsefly maximum daily totals exceeded 64,000 fish per day in 2005. An index of the total annual escapement is charted in Appendix E.

While maximum daily migration rates at Quesnel hovered around 5% of total annual escapement across the available years, this metric ranged up to 10-12% in some years at Horsefly, suggesting increased clustering of migrants between Quesnel and Horsefly locations (Table 4). Mean and quartile migration rates were, however, similar over all years between counter sites. Median (P50) daily migration rates – distinguishing “negligible” versus “low” migration – approximated <2% at both sites; the 75th percentile (P75, indicating “significant” migration) was ~3%; and the 95th percentile (P95, characterizing the threshold between “moderate” and “high” migration) was ~4-6% of the annual totals (ibid).

Summarized across all years, the mean daily migrant estimates emerged as a primarily unimodal pattern spanning 30-40 days, centered in mid-September (Figure 8 - Figure 10, top)⁴⁹. The multi-year mean time-to-50% ranged from Sep 2nd for the visual count years at the Likely Bridge to Sep 5th for Quesnel acoustic count years, and Sep 7th for Horsefly acoustic count years. This may indicate a 2- to 5-day difference for migration timing between upper Quesnel and lower Horsefly counter sites (Figure 8 - Figure 10, bottom).

Annual time-series of Quesnel/Horsefly Sockeye daily migration rates (%) were plotted in Appendix J, along with mean and maximum daily migration rates across all complete years, displaying, in some years, late onset of migration (e.g. 1993, 1997, 2001, 2005) and/or multi-modal migration pulses separated by periods of relatively low migration (e.g. 1994, 1995, 1998, 2006, 2007, 2009, 2010, 2014) which might be evidence of environmental factors influencing migration patterns.

HYDROLOGY

Quesnel River

After peak annual flows in June, the typical Quesnel/Horsefly hydrograph displays a gradual diminishing of discharge levels from early July through the migratory period

⁴⁹ Multi-modal deviations in the multi-year mean daily percentage of annual migrants (Figure 8 - Figure 10, bottom) from the mainly unimodal pattern of daily fish tallies (Figure 8 - Figure 10, top), appear to be a function of very large differences in daily migration (%) between years for a given Julian day – i.e. a higher proportion of early-timed years and late-timed years vs moderate-timed years, when the number of years is small (N<=7).

(Figure 11). Discharge levels in the lower Quesnel typically ranged from 200-400 cms (median 300 cms) by the time Sockeye are transiting upriver in mid-August (Figure 12; top), though maximum flows of 600+ cms were encountered on occasion. Minimum Quesnel flows ranged from 50-150 cms.

An apparent linear trend in observed Aug-Sep flow levels of -3.6 cms per decade ($P < 0.001$) was not statistically-significant, based on non-parametric analyses (Mann-Kendall z-statistic = -1.306, $P > 0.10$). Nor was the weak linear trend in the data since 1976 ($P < 0.10$) significant under non-parametric tests (Figure 13).

Key Aug-Sep flow percentiles in the lower Quesnel (1939-2015:1993-2015): P10=156:150 cms; P25=190:180 cms; P50=250:225 cms; P75=320:300 cms P90=390:390 cms (Table 5). The latter values in each range correspond to the recent years of available daily migration data (and hence were most applicable to defining conditions facing migrant Sockeye).

Most hydrometric station time-series in the Quesnel watershed were characterized by relatively high Aug-Sep discharge events in 1976, 1980, 1982, 1995, 1997 and 2004 (Figure 13, Figure 17, Figure 18). The Quesnel River basin also experienced high early summer flows that persisted into September in 1996, 1999-2001, such that median flows exceeded the all-year P75 level (320 cms), or else ramped up from average flows early in the migration period to exceed the P75 threshold (e.g. 1991 and 2004) (Figure 14). Of these, the only years for which daily migration data were available were 1995 (characterized by a late start to visual counts)⁵⁰, 1997 (characterized by later-than-average return timing) and 2001 (Figure 15; Appendix J; Appendix K).

At the other extreme, low water years, characterized by median flows below the all-year 10th percentile (i.e. < 156 cms) during migration, were rare in recent years, despite the declining trend in discharge. The years 1998, 2003, August 2004, 2006, 2007, and 2010 came closest (Figure 20; Appendix J), but minimum flows always exceeded 98-100 cms until late September (Table 5).

High correlation between the lower QUESNEL RIVER NEAR QUESNEL and the upper QUESNEL RIVER AT LIKELY ($r = 0.97$, $n = 692$) and the lower CARIBOO RIVER BELOW KANGAROO CREEK ($r = 0.96$, $n = 492$; Figure 23) enabled extension and/or estimation of missing values in the lower Quesnel time-series. The best fit model included both predictor variables ($r = 0.98$, $n = 492$), which applied only to the years 1926-1994, after which the Cariboo River hydrometric station was discontinued.

Estimated QUESNEL RIVER NEAR QUESNEL discharge was well-correlated with observed data ($r = 0.96$, $P < 0.001$) for the Aug-Sep time-period, though predicted values underestimated observed values for some high flow events, usually later in the season, by as much as 20% (e.g. 2000, 2004; Figure 25). This is likely a

⁵⁰ The later start date was likely due to late field program start-up rather than any high water levels or visibility issues, according to program notes. A mark-recapture tagging program and associated bridge count was not originally scheduled in 1995, which was expected to be a low return year, but was likely added based on in-season estimates at Mission in the lower Fraser.

consequence of heavy, localized autumn rains occurring in the Cariboo watershed but not captured in the upper Quesnel (at Likely) hydrometrics alone, and therefore not reflected in lower Quesnel estimates after the Cariboo station was discontinued in 1994. Fortunately, the reference station in the lower Quesnel had non-missing data that encompassed the entire Quesnel Sockeye migration time-series (1993-2015), and extends back continuously to 1939. For the purposes of covariance analyses between Quesnel flows and Sockeye daily migration (1993-present), no infilling was therefore required. For discharge exceedance analyses, estimated flows comprised only the pre-1939 years, for which Cariboo discharges were available.

Observed/estimated daily discharges for the migratory period were aligned with other environmental variates and the daily migration index in Appendix J.

Horsefly River

Observed flows in the lower HORSEFLY RIVER ABOVE QUESNEL LAKE during the migratory period were generally an order of magnitude lower than Quesnel. Mean flows ranged from 20-30 cms, and maxima of 50-100 cms occurring in conjunction with early fall rains (Figure 11, Figure 12; bottom). Key percentiles in the observed data (2004-2015) were: P10=8 cms; P25=10 cms; P75=20 cms; P90=30 cms (Table 6). Aug-Sep flows appear to be declining in the Horsefly and its major tributary, McKinley Creek, since the 1960s, possibly more steeply since 2004 (Figure 16 - Figure 18).

High correlation between the lower HORSEFLY RIVER ABOVE QUESNEL LAKE and the upper HORSEFLY RIVER ABOVE MCKINLEY ($r = 0.97$, $n = 72$), MCKINLEY CREEK ($r = 0.95$, $n = 81$), and MOFFAT CREEK ($r = 0.93$, $n = 63$) enabled extension and/or estimation of missing values in the lower Horsefly time-series based on log-log least squares regression models (Figure 26 - Figure 29). The best fit model was multi-variate, which retained only MCKINLEY and MOFFAT predictor variables ($r = 0.99$, $n = 63$); estimated data were highly correlated with observed (Figure 30). The resulting time-series of observed and estimated lower Horsefly River discharge extended continuously from 1964-2015, with a declining trend of ~2-3 cms per decade (Figure 50).

Associated with the declining trend, seasonal mean flows exceeded the P90 threshold more frequently in first 25 years of the time-series (1964, 1969, 1976, 1980, 1982, 1984) than the last 25 years (1995, 2004).

Extreme low water years during migration, characterized by median flows below the all-year 10th percentile (i.e. < 8-10 cms), were more evenly distributed over the past 5 decades (1967, 1970, 1979, 1985, 1986, 1987, 1988, 1990, 1992, 1998, 2003, August 2004, 2006, 2007, and 2015) (Table 7). Extreme high water years during migration, characterized by median flows above the all year 90th percentile occurred in 1982, 1995, Sep 2004, 2008. Of these years, Horsefly-specific daily migration data were only available for 2006 and 2007 – for which no obvious impacts on daily migration pattern were apparent.

WATER TEMPERATURE DATA

Quesnel River

Observed Quesnel River water temperatures between 2006 and 2012 were found not significantly different between sites QR-1 and 08KH006 based on paired t-tests and ANOVA, and were highly correlated ($r = 0.98$; $P < 0.001$; $n = 557$; Figure 33). The linear statistical relation was used to infill missing data at site QR-1 from 2006-2012 and extend the water temperature dataset from 2013-2015. The consolidated temperature dataset was used in air/water regression analyses for the Quesnel River.

The annual time-series of Quesnel River water temperature observations were plotted by year and site (at QR-1 and 08KH006) in Appendix H. The annual plots were condensed in Figure 32 and statistically summarized for the lower Quesnel reference site in Figure 34.

Mean temperature during Sockeye migration for the resulting time-series was $15.6 \pm 2.1^{\circ}\text{C}$, with 95% of water temperatures less than 18.8°C (Table 8; Figure 32). The summers of 2003, 2004, and 2013 were consistently represented in the warmest years of observed data for various temperature indices (e.g. mean, maximum, 75-95th percentiles). Observed water temperatures exceeded 20°C for approximately 10 days in early August in 2013 (Appendix H).

Fraser River at Qualark (FR-190) reconstructed water temperatures (Patterson et al. 2007) were summarized in Table 10 (1941-2011, 1946 and 1949 missing). Maximum water temperatures during the migration period (July-August-September) ranged from 16 - 21°C , but the 1940s, 1990s, and 2000s represented the warmest decades, where the P95 (95th percentile) of summer water temperatures equaled 19.0°C or more. Warmest years ($P95 > 20^{\circ}\text{C}$) included 1941, 1981, 1992, 1998, 2003, 2004, 2006, and 2009.

Covariation between the lower Quesnel River and the Fraser River at Qualark ($r = 0.84$; $n=631$) indicated that temperatures in the mid-Fraser were generally 2 - 3°C warmer than the lower Quesnel during Sockeye migration (Figure 37; top). Though this does not account for the travel time while traversing ~ 550 km of the lower- and mid-Fraser, it does suggest that Sockeye encountering the upper extreme (16 - 18°C) of Quesnel temperatures likely had already been exposed to temperatures in the range of 18 - 20°C between Qualark to Quesnel.

Horsefly River

Observed lower Horsefly River water temperatures during the migratory period (August-September) averaged about a degree cooler than the lower Quesnel when matched by year, with cooler minima and warmer maxima (i.e. a wider range of temperatures) than the larger Quesnel River.

Observed lower Horsefly temperatures for all available years averaged $14.0 \pm 3.1^{\circ}\text{C}$, with 95% of temperatures below 18.9°C (Table 9). Horsefly River water temperatures typically reached their maximum in early-August where daily mean temperatures briefly averaged 13 - 14°C (Figure 35; Appendix I). The summers of 1998, 2003, 2004, and 2009 were consistently represented in the warmest years of

observed data for various temperature indices (e.g. mean, maximum, 75-95th percentiles) (Table 9). In 2004, elevated water temperatures commenced in mid-July and after a brief reprieve, extended through mid-August as well (Appendix I).

Statistical relations between Horsefly River (HR-22) and Quesnel River (QR-1) temperatures were not linear across warming and cooling seasons (Figure 36), indicating a hydrologic size-based difference in hysteresis effects between the two sites.

The linear relation between the lower Horsefly and Fraser at Qualark ($r = 0.91$, $n=891$) suggested that, at the upper end of Horsefly water temperatures, Sockeye migrants probably experienced temperatures at least 1-2°C higher in the Fraser (Figure 37; bottom), though this does not account for the 4-9 day travel time through Quesnel River and Quesnel Lake.

WATER TEMPERATURE TIME-SERIES RECONSTRUCTION

Quesnel River

The logistic and linear air/water temperature models for the lower Quesnel River (QR-1 Reference Site) were parameterized using a calibration dataset composed of 10 years of data between 2000 to 2015 (Table 11).

SEASONAL TURN-AROUND POINT

The mid-year seasonal turn-around point for lower Quesnel River was derived as week 30 (day 210), approximately August 2nd – based on maximum mean weekly air and water temperatures for the calibration data years (Figure 38). The “warming season” therefore extended from April 1 to August 2nd, followed by the “cooling season” from day 211-329, i.e. August 3rd – November 25th.

MULTI-DAY AIR TEMPERATURE INDEX

The multi-day QUESNEL air temperature index that best correlated with all-year daily mean water temperature in the lower Quesnel River was identified as the 7-day centered moving average air temperature index (7d-CMAT).

For the warming season, calibration dataset correlations were marginally improved with increasing length (no. of days) in the multi-day moving average, reaching a maximum with the 10-day MAT (Figure 39 (top); $r_{5d-CMAT} = 0.89$; $r_{7d-CMAT} = 0.90$; $r_{10d-CMAT} = 0.91$; $P < .0001$; $n = 477$). For the cooling season, maximum correlation was achieved with the 7-day MAT index (Figure 39 (bottom); $r_{7d-CMAT} = 0.83$; $P < .0001$; $n = 320$). As the 10-day CMAT was rejected⁵¹, the QUESNEL 7-day moving average temperature index was used for subsequent air/water temperature analyses.

MODEL CALIBRATION AND VALIDATION

Hysteresis was detected for logistic relations for the Quesnel River calibration dataset (Table 11) based on the difference between seasonal and all-season

⁵¹ The 10-d CMAT index was excluded due to the undesired trade-off between high correlation versus the damping effect on daily air temperature variation and resulting daily water temperature estimates (Hyatt et al. 2015).

goodness-of-fit (NSC) coefficients (Table 12), as well as for linear relations based on significance tests for equal intercepts and equal slopes (Table 13), indicating that air/water temperature relationships were best modeled using separate seasonal components (logistic models: Figure 40; linear models: Figure 41). Logistic model parameters, 95% confidence limits, and NSC goodness-of-fit coefficients are listed in Table 12. Linear regression model output for seasonal air/water temperature relationships and calibration data are provided in Table 13.

A subset of the validation data years were plotted in Figure 42 with observed and logistically-modeled MWT output, along with daily MAT and the 7-d MAT index (linear output not shown). Average conditions were estimated reasonably well (e.g. 2001, 2003, 2008), as were non-extreme monthly statistics such as the median and other percentiles (10th, 75th, 95th) (Table 15). Both model-types tended to underestimate water temperatures in warm years (e.g. 2013), thereby yielding conservative estimates of the frequency and duration of the warm water periods. Depressed water temperature (e.g. 2000, 2011) were generally not modeled well either. Season-specific Pearson (least squares) and Spearman (rank) correlation coefficients between modeled estimates and validation data are contrasted in Table 14. Correlation coefficients for validation data ($r \sim 0.85$) indicated that linear and logistic model types were essentially equivalent in their skill at predicting lower Quesnel River water temperatures.

For the purposes of establishing a long-term water temperature index, and for consistency with analyses in other studies (e.g. Hyatt et al. 2015), the seasonal logistic model parameters were selected as the best estimators of daily mean water temperature for lower Quesnel River, and were used to reconstruct historical daily water temperature estimates for the period of available air temperature data (1940-present: Table 15).

Horsefly River

The logistic and linear air/water temperature models for the lower Horsefly River were parameterized using a calibration dataset composed of ten years of data between 1990 to 2009 (Table 17).

SEASONAL TURN-AROUND POINT

The mid-year seasonal turn-around point for Horsefly River was also derived as week 30 (day 210), approximately August 2nd – based on maximum mean weekly air temperature at QUESNEL for the calibration data years (Figure 43). The “warming season” therefore extended from April 1 to August 2nd, followed by the “cooling season” from day 211-329, i.e. August 3rd – November 25th.

MULTI-DAY AIR TEMPERATURE INDEX

The multi-day QUESNEL air temperature index that best correlated with all-year daily mean water temperature in lower Horsefly River was identified as the 10-day centered moving average air temperature index (not shown) (warming season: $r = 0.90$; cooling season: $r = 0.94$). However, the 7d-CMAT index was selected for subsequent air/water temperature analyses based on high correlations (warming season: $r = 0.89$, $n = 948$; cooling season: $r = 0.93$, $n = 578$), and for consistency

with air-water temperature relations for the Quesnel River reference site.

MODEL CALIBRATION AND VALIDATION

Hysteresis was detected for logistic relations based on the difference between seasonal and all-season goodness-of-fit (NSC) coefficients. Logistic model parameters, 95% confidence limits, and NSC goodness-of-fit coefficients are listed in Table 18. Hysteresis was also detected for linear relations based on significance tests for equal intercepts and equal slopes (Table 19), indicating that air/water temperature relationships were best modeled using separate seasonal components (logistic models: Figure 44; linear models: Figure 45).

A subset of the validation data years were plotted in Figure 46 with observed and logistically-modeled MWT output (linear output not shown), along with daily MAT and the 7-d MAT index. The model tended to over-estimate actual water temperatures during the warming season (e.g. 1996). Rapid drops in water temperature that occasionally characterize Horsefly outflows (e.g. 1997) were not modelled well, but average conditions were reasonably estimated (e.g. 2000). Season-specific Pearson (least squares) and Spearman (rank) correlation coefficients between modeled estimates and validation data are contrasted in Table 20. Correlation coefficients for validation data ($r \sim 0.92$) indicated that logistic model types were reasonably skillful at predicting lower Horsefly River water temperatures.

TEMPERATURE, FLOW, AND MIGRATION

Trends in Temperature

A weak long-term warming trend in the regional air temperature index at Quesnel was evident for the summer months (August-September) over the 116 year period (1900-2015) (Figure 47, top). However, the linear trend was less than a tenth of a degree per decade ($r = 0.06$, $P < 0.001$)⁵². The results from two non-parametric trend analyses differed – Spearman's rho test statistic was significant ($z = 2.0$, $P < 0.05$), while the Mann-Kendall test showed no trend ($z = 1.6$, $P > 0.10$). The long-term air temperature mean for these summer months was 13.9°C, however, multiple air temperature regimes were evident: regime step-change statistics suggested that air temperatures were cooler in the early 1900s (~12.5°C 1900-1914) than afterwards (~14.4°C), but included a 1-degree dip in temperature between 1943 and 1987 (~13.5°C) (Figure 47, bottom). The non-parametric rank-sum statistic identified significant step-changes in the mean at 1913, 1976, and 1987, but not at 1943.

Both Quesnel and Horsefly River mean water temperature estimates necessarily indicated a weak linear warming trend as well (Figure 48), since these estimates are dependent on the air temperature time-series. Non-parametric analyses indicated that mean Aug-Sep water temperatures (~14°C in the lower Horsefly, ~15°C in the less variable lower Quesnel) did not change significantly over the period 1900 and 2015 (Table 15, Table 16), though they likely reflected the decadal temperature shifts identified in the air temperature regime analysis (Figure 47, bottom).

⁵² Burford et al. (2009) found no significant trend in *mean annual* air temperature in the Quesnel watershed, but an increasing trend in *mean minimum* temperatures that is greatest in winter.

Trends in Discharge

The extended time-series of observed (1939-2015) plus estimated (1924-1938) discharge in the lower QUESNEL RIVER showed no significant trends for the adult migration months combined, or for July, August or September separately (Figure 49), according to parametric and non-parametric analyses. Limiting the dataset to 1964-2015 (for comparison to the lower Horsefly discharge time-series) indicated a significant decline of 12 cms per decade (Mann-Kendall z-score = -2.06, $P < 0.05$), with a statistically-significant negative step in mean discharge in 1984 (rank sum z-statistic = 1.984, $P < 0.05$), approximately corresponding to the period when mean air temperatures in the watershed stepped up. However, serial t-test analysis (STARS) did not define any regime shifts in the lower Quesnel time-series, including the 1984 step-change.

The decline in flow levels since the 1960s was also reflected within and across all summer months in the Horsefly watershed (Figure 50). Lower Horsefly discharge (observed plus estimated) decreased during August and September by approximately 3 cms since 1964 (Mann-Kendall $Z = -1.996$, $P < 0.05$), with strongest decreases in August (Mann-Kendall $Z = -2.47$, $P < 0.05$). A statistically-significant negative step in mean discharge was also detected at 1984 (rank sum $Z = 2.21$, $P < 0.05$). Again, serial t-test analysis for regime shifts did not define the step-change as a new regime.

Migration in Relation to Temperature and Discharge

A heat map of the distribution of non-parametric CMH-GA⁵³ statistics was used to help identify, for each environmental variable, the time lags and threshold levels most associated with large changes in migration rate at the Quesnel and/or Horsefly River Sockeye counter sites.

Outputs were generated for Quesnel River migration data (combined visual and acoustic data) in relation to lower Quesnel water temperature, stratified by discharge category (Figure 51), and for migration in relation to discharge, stratified by water temperature category (Figure 52). Statistical effects were similar at temperature thresholds in the range of 16-18°C, and insufficient data at 19°C or more, thus only the 17°C threshold analysis is displayed.⁵⁴

The CMH-GA discharge-stratified distribution in Figure 51 indicated significant statistical association ($P < 0.05$) between migration data lagged 4 days and lower Quesnel River water temperature (at threshold level of 17°C), stratified across discharge thresholds. This suggests a potential "temperature effect" associated with changes in migration four days later at a wide range of discharge levels, with maximum statistical significance below 270 cms and above 340 cms thresholds. The

⁵³ The COCHRAN-MANTEL-HAENSZEL GENERAL ASSOCIATION statistic provides a stratified frequency analysis of the level of association between the migration rate response classification (high vs low migration categories) and independent environmental classes (high/low temperature and discharge classes) to control for confounding effects of water temperature and discharge.

⁵⁴ At 16°C, the CMH-GA statistics were not significant; at 15°C, the statistic was marginally significant at a lag of six days at 325 cms.

contingency table for these thresholds typically indicated that at higher discharge rates (above the threshold), few fish were migrating, and fewer still at high temperatures ($>17^{\circ}\text{C}$) (e.g. Table 21).

The temperature-stratified distribution in Figure 52 indicated highly significant statistical association ($P < 0.001$) for migration in relation to discharge level at the 17°C water temperature threshold, across a variable range of lower Quesnel River discharge thresholds. Maximum significance varied with both discharge level and migration data lag, ranging from 340-350 cms 4-6 days prior to being counted in the upper Quesnel River, to 280 cms 2-3 days prior. This posits the existence of a "discharge effect" at relatively high flow levels influencing migration rates 4-6 days later, with similar effects 2-3 days later at lower flow levels. Contingency tables at coordinates typical of threshold values of maximum significance indicated the greatest frequency of high migration activity ($>5\%$ per day) occurred at lower discharges and temperatures $< 17^{\circ}\text{C}$ (Table 22).

The CMH-GA statistics for Sockeye migration data collected via DIDSON acoustic counters in Horsefly River in conjunction with lower Quesnel river conditions were only weakly statistically-significant ($P = 0.08$), but showed maximum association when migrant data were lagged back in time nine days (not shown), suggesting a five-day time-lag between Quesnel and Horsefly sites. Combining the Horsefly migration data (lagged back five days) with Quesnel migration data yielded CMH-GA heat maps very similar (not shown) to those for Quesnel migrant data alone (Figure 51; Figure 52).

These results generally suggest that conditions in the lower Quesnel River, approximately four days prior to fish passage in the upper Quesnel, were at times significantly associated with variation in daily migration rates, especially at higher flow levels of 330-370 cms. At lesser flows, the effect is either closer to the counter site, or the fish are moving faster.

Analysis of daily changes in migration data from the Horsefly counter site in conjunction with conditions in the Horsefly River indicated a weak but consistent statistical association with water temperature across all discharge levels three days prior ($0.05 < P < 0.10$; Figure 53). When water temperature was held constant (at 15°C), significant differences in Sockeye migration were also associated with discharge at very low flow levels (~ 8 cms) 6-7 days before reaching the counter site, and across a range of higher discharge levels (14-30 cms) five days prior (Figure 54; shaded areas: $P < 0.05$). Though limited to four years of acoustic count data, these results are suggestive of some kind of Quesnel River discharge effect over the week prior to passage, and a temperature effect in the vicinity of the Horsefly counter site, perhaps related to fish movement into the Horsefly River itself.

An un-weighted tally of non-zero migration dates indicated that approximately 77% of the historic migration dates occurred when lower Quesnel flows four days earlier were ~ 150 -250 cms (Figure 55). Weighting the frequency distribution by the daily migration rate indicated that, ignoring infrequent occurrences, significant daily migration rates ($>3\%$) occurred at discharge levels up to 350-400 cms (Figure 56).

Dates of migration activity were approximately normally-distributed around 16°C ,

with the majority of dates (~75%) characterized by water temperatures of 15-17°C (Figure 57). Highest mean daily migration rates (i.e. >3% per day) were also associated with estimated water temperatures of 15-17°C (Figure 58).

A weighted two-way frequency distribution based on combined flow and temperature ranges showed that high migration rates were found at a range of discharge and temperature levels, with maxima at 15-17°C and 150-250 (Figure 59).

An upper flow threshold of 375 cms – approximating the 90th percentile of lower Quesnel River daily discharge – was subjectively identified from these analyses for subsequent exceedance analyses. A lower threshold of 8 cms (~10th percentile) for Horsefly flows was also identified for 'peak under' exceedance analyses.

SPAWN TIMING – ARRIVAL VS PEAK SPAWN DATE

Horsefly Sockeye spawn timing data provided further, though limited, information regarding the association of environmental conditions with migration patterns.

The significance of the correlation between Arrival Time and Peak Spawning Time varied, depending on which cycle lines were included in the analysis (Figure 60). Including all cycle lines indicated a significant relationship ($r = 0.42$, $P = 0.001$, $n = 49$; Figure 60: top), suggesting roughly 10-20 days between arrival and peak spawn activity, depending on time of arrival. However, this relationship assumes within-year arrival and spawning dates are reasonably comparable despite known between-year differences in field effort. Furthermore, it may be driven by influential data points for 1940 and 1976 which were characterized by extreme late arrival (>P95).

Omitting off-cycle years yielded a weaker relationship ($P = 0.10$, $n = 31$), due to the presence of late-arrival observations in 1950, 1954, 1962 and 1970, which were associated with immediate spawning that peaked within 5-10 days (Figure 60: middle). Omitting the sub-dominant cycle line excluded these 'outliers', and resulted in a statistically-significant relationship between the timing indices ($r = 0.69$; $P = 0.002$; $n = 17$), suggesting that peak spawning occurs ~25 days after arrival during the dominant cycle line (Figure 60: bottom).

SPAWN TIMING – TIME TRENDS

Eighty percent of annual spawner arrival dates (across all cycle lines⁵⁵) occurred between August 8th and 25th, with median date of arrival August 15th (Figure 61; top). A weak, positive, time trend in Arrival Time and a strong trend in Peak Spawning Time, apparent in the all-cycle-line data, were statistically-improved when data were restricted to dominant cycle lines only (Figure 61; middle, bottom).⁵⁶ Non-parametric trend statistics indicated positive step-changes in mean timing occurring in the late

⁵⁵ Recall that off-cycle years are not directly comparable to dominant/sub-dominant cycle lines.

⁵⁶ Dominant cycle line linear time trend in Arrival Timing (1940-2015): $r = 0.46$; $P = 0.04$, $n = 17$. Non-parametric statistics: Mann-Kendall $Z = 2.3$; $P < 0.01$, $n = 17$; with a positive step change between 1973 and 1977 (Rank Sum $Z = -2.6$, $P < 0.01$), or at 1985 (Cusum $P < 0.05$).

1970s or early 1980s.⁵⁷

Early arrivals (date < P10, ~August 6th) were most frequent in the 1950s and 1960s, and not observed after 1970 (Figure 61; middle). All of the observed years of late time of arrival (>P90, ~August 25th) for the two dominant cycle lines (e.g. 1950, 1954, 1962, 1970, 2002 and 2013; Figure 61; middle) were associated with the sub-dominant cycle line (*cf.* Figure 61: middle with Figure 61: bottom). Of these, only 1954 and 1962 were characterized by environmental extremes in the Quesnel system, specifically above-average discharge in August (visual inspection: Figure 48; Figure 49; Figure 50).

A confounding factor may involve annual escapement abundance – which is positively related to Arrival Time and significantly related to Peak Spawn Time ($r^2 = 0.38$, $P < 0.01$, $n = 32$), even when data were restricted to dominant and sub-dominant cycle lines for years where the number of effective females exceeded 200,000 fish (Appendix G).⁵⁸

SPAWN TIMING – TEMPERATURE AND DISCHARGE

When data were restricted to dominant/sub-dominant cycle lines, Arrival Time was not correlated with either Quesnel River or Horsefly River water temperatures. Nor was Arrival Time correlated with Quesnel River discharge levels.

However, both Arrival Time and Peak Spawn Time were negatively correlated with discharge indices such as median August and September flows in Horsefly River (Table 24)⁵⁹. Maximum correlations for Arrival Time occurred in relation to indices of low flow in August (e.g. P25th percentile; $r = -0.63$, $P = 0.0017$, $n = 25$; Figure 62), and high flow in September (e.g. max. flow; $r = -0.59$, $P = 0.0037$, $n = 25$; Figure 63).

For Peak Spawn Timing, the correlation pattern was similar (Table 24; Figure 64, Figure 65)⁶⁰. This implies that low flows were associated with later arrival time on the Horsefly spawning grounds, and consequently, later timing for peak spawning activity. When restricted to dominant cycle line years only, the correlation patterns were consistent, though statistically-weakened, likely due to the reduction in observations ($12 \leq n \leq 13$).

Returning to the limited daily migration data available, anomaly plots of migration

⁵⁷ Dominant cycle line linear time trend in Peak Spawn Timing (1940-2015): $r = 0.75$; $P < 0.01$, $n = 17$. Non-parametric statistics: Mann-Kendall $Z = 3.2$; $P < 0.01$, $n = 17$; with a positive step change between 1973 and 1977 (Rank Sum $Z = -3.1$, $P < 0.01$), or at 1981 (Cusum $P < 0.01$).

⁵⁸ Whether high fish densities on the spawning grounds affect spawn timing is unclear. However, any apparent trend in either timing index must account for this evident relationship since large abundances in the available time-series have only been recorded since the 1980s, and thus are driving the positive time trend.

⁵⁹ When restricted to dominant cycle line only, patterns remained at lower statistical significances due to reduced sample size.

⁶⁰ Inverse correlations for Peak Spawn Timing with September Quesnel River flow indices were also evident for dominant/sub-dominant cycle lines ($P < 0.04$, $N = 36$), with maximum negative correlations at P90 and P100 (maximum) Quesnel flow indices ($r \sim -0.44$, $P < 0.01$, $N = 36$). Not shown.

rate versus water temperature and discharge deviations based on lower Quesnel environmental thresholds of 17°C and 350 cms (for exploratory purposes) four days earlier (Appendix K) indicated that the most consistent environmental impact in the historical data was the delay in the onset of migration due to high discharge levels. When high Quesnel flows persisted into the migratory period, moderate-to-high migration rates (> 3% per day) were generally inhibited until daily mean discharge dropped below 350-400 cms. This effect was evident in 1995 and 2001 (Appendix K). In other years of high early flows (1999-2000, 2003, 2011), no daily migration data were available.⁶¹

At the low end of the flow spectrum, it was observed that high migration rates were not evident in the data below ~150 cms (~10th percentile); however, this was most likely because the lowest water levels generally occurred late in September, near the end of the Sockeye run. When low discharge commenced early in the season in 1998, 2006, 2007, 2010 and 2015, the daily migration timing window did not deviate from the multi-year average, but there was evidence of one or more migration interruptions, possibly related to low flows interacting with temperature (Appendix K).

Direct effects of high temperature were less evident in the daily migration data, which were only available for a few (specifically: late 1995, and early 1998) of the 'warm years'.⁶² Across all years, Quesnel water temperatures rarely exceeded 19°C; the 95th percentile of observed/estimated values was 18.8°C.⁶³ Apparent increases in migration from moderate to high levels as temperatures fell below 17-18°C were possibly evident for some years, in which high flows were not a factor (e.g. 1998; 2005; Appendix K).

Late Arrival Time in 2013 may be linked to high August temperatures, but moderate temperatures and flows characterized conditions for delayed migration timing in 1993, 1997, and 2005, and late arrival recorded for 2002. For other years, intermittent migration stoppages and delays do not appear to be related to temperature or flow in the Quesnel watershed (2009, 2010, 2014). Some or all of these patterns may be an 'indirect' effect of stressful conditions (high flows, water temperatures several degrees warmer) affecting migration in the Fraser, or marine environmental influences affecting return timing to the terminal Fraser estuary.

Temperature Exceedance Analyses

A frequency analysis of regional daily mean air temperature indicates that the annual cumulative total number of POT_{>20°C} dates has averaged 3-4 days per year for most of the century, with no statistically detectable difference between decades (Figure

⁶¹ The Arrival Time index was not available for 1999-2000. Arrival Time in 2003 and 2011 were recorded as late (>P90 of Julian dates; Appendix F), but refer to non-dominant cycle years, for which spawn timing data are unreliable.

⁶² In recent decades, Quesnel water temperatures in Aug-Sep were above average for: 1990, 1995, 1998, 2003, 2004, 2009, 2013.

⁶³ Observed Horsefly water temperatures exceeded 20°C much more frequently, particularly in the 'warm years' of 1998, 2003, 2004, 2009, and 2013, but daily migration count data were not available for these years.

66). The 1900s and 1950s were characterized by cooler weather, with less than 1 day per year exceeding 20°C. While the duration of continuous POT_{>20°C} periods has remained less than 2-3 days on average over the past eleven decades, warmer periods (1910s – 1940s; and 1960s-2000s) showed a high frequency of such periods (Table 25, Figure 67).

A similar frequency analysis based on estimated daily mean water temperature exceeding 18°C in the lower Quesnel River during migration (August-September) indicated that the cumulative total number of POT_{>18°C} dates per year fluctuated from 4-6 days per year on average, almost exclusively in August (Figure 68; Table 26, top).⁶⁴ However, none of these differences are statistically significant ($P > 0.05$).

The average length of Quesnel River POT_{>18°C} periods was less than 7 days for most decades, with no apparent trend, though since the 1960s, the frequency of such periods has returned to about once per year, similar to the warm cycle 1910s-1930s (Figure 69, Table 26, bottom). Years with extended periods of elevated Quesnel River water temperature included: 1941 (15 days); 1967 (15); 1971 (12); 1981 (19); 1990 (16), 1991 (15), 1998 (8), 2004 (9), and 2013 (14) (Table 27).

In the lower Horsefly, the frequency of POT_{>18°C} dates per year averaged 6-8 days per year during the warm periods, slightly more than the lower Quesnel on account of the smaller Horsefly river being more responsive to temperature changes (Table 28, top; Figure 70). While the mean length of continuous POT_{>18°C} events in the Horsefly (5-7 days) did not differ much from the Quesnel summary, the frequency of POT_{>18°C} events of that length was up to 25% greater in the smaller river (Table 28, bottom; Figure 71). And while the years with extended periods of elevated water temperatures in the lower Horsefly (>10-14 days) mirrored the Quesnel results, the Horsefly POT_{>18°C} periods were generally longer by a day or two in each case (e.g. the warm period in 1990 extended 18 days; Table 29).

Discharge Exceedance Analyses

Low flow periods (POT_{<8 cms}), based on the 10th percentile of flow data from the HORSEFLY ABOVE QUESNEL LAKE hydrometric station, have occurred mostly in September (Table 30). The decadal frequency of low flow dates since the 1970s has averaged about 5-7 days per year, without evidence of time trend or significant differences between decades (Figure 72)⁶⁵. Drought-like years, where low Aug-Sep discharge dates were most frequent, included: 1970, 1979, 1987, 1992, 1998, 2003, 2006 and 2015 (Table 30).

Continuous POT_{<8 cms} events of ~7 days in length occurred on average less than once a year (Figure 73). The longest stretches (>21 days) occurred in 1979, 1987, 1998, 2003 and 2006 (Table 31). More recently, during the 1990s and 2000s, the average frequency and duration of low flow events has increased to ~10 days (not significantly, however), with a higher proportion in the month of August, indicative of

⁶⁴ A POT_{>18°C} analysis yielded no tallies, and a POT_{>17°C} analysis yielded no tallies prior to the 1960s, and less than 2 tallies per year for all decades since then, with no trends.

⁶⁵ 1960s discharge summary not directly comparable to other decades – only 5 years available.

drier summers in recent decades.

Very high flow dates ($>85^{\text{th}}$ percentile of daily discharge at QUESNEL NEAR QUESNEL⁶⁶) have generally occurred about 5-10 days per year – principally in August – with no apparent trend in the long-term annual frequency (Figure 74). Though not significantly different from other decades, the 1960s exhibited the highest frequencies of $\text{POT}_{>375}$, at ~ 11 dates per year, largely driven by high flows in 1962 and 1964 (28-32 days per year; Table 32) that persisted through August into September. This happened again in 1976 and 1982. Consistently high August flows returned in the late 1990s up to 2001, with the notable exception of the warm, dry year 1998, which experienced no flows $> 85^{\text{th}}$ percentile in August-September (Table 32). The overall frequency of high flows decreased in the 2000s to less than 1 week per year as Quesnel River discharge levels trended downward, though that average obscures some years of relatively high flow frequencies (2001: 26 days; 2011: 17 days; and the somewhat anomalous 2004: 13 days, all of which were in September)(Table 32).

The average duration of continuous $\text{POT}_{>375}$ dates reached its decadal maximum in the 1960s at ~ 15 days per year (Figure 75; Table 30). The persistence record was set in 1976 at 49 days, which entailed all of August and the first 18 days of September; followed by 1962 (32 days) (Table 32). Sockeye count years in which the first 3-4 weeks of migration were met with high Quesnel flows included 2001 and 2011; no migration delays were evident in 2001, while 2011 was characterized by some evidence of delay in the onset of significant migration activity (Appendix J).

DISCUSSION

The influence of environmental factors on upstream migration of Fraser salmon has been widely documented. Water temperatures have been found to be correlated with metabolic stress, impaired swimming capacity, and vulnerability to disease, resulting in increased enroute mortality (Macdonald et al. 2000a; 2000b). Furthermore, water temperatures in the Fraser have been rising steadily (Martins et al. 2010; 2012; Patterson et al. 2007) and are projected to continue to rise (Whitfield 2001; Whitfield et al. 2002), escalating the impacts on Sockeye population sustainability (Hinch and Martins 2011) and fisheries management (Hague and Patterson 2007; Young et al. 2006). An increase in the frequency of flow extremes is another outcome of climate variation in the Fraser watershed (Whitfield and Cannon 2001), which can exacerbate thermal impacts on fish condition and survival (Rand et al. 2006).

As is the case for other Fraser salmon stocks, Horsefly-bound Sockeye that survive the Fraser leg of freshwater migration must have sufficient energy reserves to meet the physical demands associated with the unique environmental conditions in the terminal tributaries enroute to their natal spawning grounds. For example, from the Fraser/Quesnel confluence to the spawning grounds (~ 160 km), Horsefly Sockeye must climb 300-400 m to their final elevation in the lower Horsefly River or McKinley

⁶⁶ Corresponding to ~ 375 cms in the lower Quesnel River.

Creek, after traversing through multiple 'canyons' of rapids. This energetically-demanding leg of the journey represents the last 20% of their freshwater migration distance but accounts for 40-45% of the total vertical ascent from sea level.

The cumulative environmental impacts on migrants to this point are likely exacerbated by concentrated flows at hydrological focal points (Burnett et al. 2014) such as within the Quesnel Canyon. High water velocity associated with river discharge has been correlated with higher energy expenditures (Salinger and Anderson 2006), enroute mortality (MacDonald et al. 2000a; 2000b), slower migration rates (Hinch and Rand 1998), and migration delays (Fenkes et al. 2016). Migrants are more likely to succumb to pre-spawn mortality after high-flow-induced 'burst swimming' efforts to traverse hydraulically-challenging locations (Burnett et al. 2014; Hinch et al. 2002), such as at Hell's Gate in the Fraser River ~350 km downstream of the Quesnel River confluence.

High pre-spawn mortality rates, documented in 1953 (30%), 1961 (62%), 1965 (47%), 1969 (49%), and 1973 (27%), were associated with elevated water temperatures and infectious microbial disease outbreaks on the Horsefly spawning grounds (IPSFC 1966; Williams 1973a, 1973b; Williams et al. 1977; Roos 1991 in: Grant et al. 2011). In an attempt to mitigate the impacts of elevated water temperatures, a dam was constructed at the outlet of McKinley Lake in 1969 with a siphon system to deliver cooler water from the lake hypolimnion (~2°C cooler) to Horsefly spawning grounds via McKinley Creek (IPSFC 1966; Mead 1969; Cooper 1973).⁶⁷ However, fisheries staff found that the temperature-moderating capacity of the McKinley Lake siphon discharge was largely restricted to McKinley Creek, and undetectable at the lower Horsefly River datalogger (MacDonald et al. 2000b). Bacterial disease outbreaks occurred again in 1997 and 1998), and spawning success was less than 70% in 2008 and 2011, and below 35% in 2012 (Fraser Stock Assessment). Thus, the Quesnel Sockeye stock has remained susceptible to temperature-related pre-spawn mortality and reduced fertilization success and hatching rates, despite siphon operations (MacDonald et al. 2000b).

SOCKEYE MIGRATION AND WATER TEMPERATURE CONDITIONS

As environmental impacts on Sockeye migration attributable to Fraser River conditions – especially the thermal effects briefly outlined above – are explored elsewhere (e.g. in the lower and mid-Fraser and/or at Hell's Gate: Patterson et al. 2007; MacDonald et al. 2000a, 2000b; Martins et al. 2011, etc.), this section will focus on whether available migration timing data sheds further light on possible impacts in the Quesnel/Horsefly watershed.

After exiting the Fraser River into the Quesnel watershed (which tends to be 2°C

⁶⁷ A 168-cm diameter pipeline siphon 732 m in length, originating in the bottom of McKinley Lake, was designed to mix hypolimnetic and surface waters at the dam for release into McKinley Creek in order to cool spawning grounds in the upper Horsefly River (Rood & Hamilton 1995; Holmes 2009). While utilized during dominant and sub-dominant cycle lines extensively during the 1980s and 1990s, the system fell out of use after 2004/2005 (pers. comm., Doug Turvey, Spius Creek Hatchery manager, 2006-2015). For details on the history and function of the McKinley Dam siphon, see Appendix L.

warmer than the Quesnel), the warmest water temperatures experienced by Horsefly-bound Sockeye tend to occur in the lower Horsefly River, where observed temperatures have been known to exceed 22°C as Sockeye arrive to spawn. Daily maximums in the Horsefly River during summer months can be a degree or two warmer than the much larger Quesnel River, which is slower to change due to large inputs from the glacier-fed Cariboo watershed. For example, the 95th percentile of observed daily mean water temperatures did not exceed 20°C in the Quesnel between 2000-2012, as it did in the Horsefly in 1998, 2003, 2004 and 2009 (Figure 34, Figure 35; Appendix I). On the other hand, due to lower daily temperature variation in the larger Quesnel River, *median* and *average* Quesnel temperatures were 1-2 degrees warmer ($15.6 \pm 2.1^\circ\text{C}$) than the Horsefly ($14.0 \pm 3.1^\circ\text{C}$) during the migration period (Table 8, Table 9).

A strong statistical correlation with WSC water temperature data was used to infill missing data in the EWP time-series in the lower Quesnel (2000-2012) and to extend it to 2015. The resulting temperature dataset was used in logistic regression analyses to generate an index of Quesnel River daily mean water temperature from regional air temperature encompassing the record of daily Sockeye migration (since 1993) – and back to 1900 for trend analyses. This daily water temperature index⁶⁸ provides a standardized estimator across all years which reasonably reproduces observed temperatures in most years.

The regression analysis is based on a wide variety of years, such that predictive estimates tend to underestimate occasional rapid changes (e.g. 1997, 1998) and/or persistent extremes (e.g. 2004) in water temperature in some years.⁶⁹ Thus, the results of analyses regarding average and peak temperatures, including exceedance analyses of frequency and duration over temperature thresholds (Figure 68; Figure 69), must be considered conservative, though inter-annual and decadal trends should be consistent.

Given these qualifications, it appears that estimated mean water temperatures in the lower Quesnel and Horsefly Rivers during the Sockeye migratory period are currently $15.5 \pm 2^\circ\text{C}$ and $14.0 \pm 2^\circ\text{C}$, respectively, and have been rising at a statistically-insignificant rate of approximately 0.1°C per decade since the 1900s (Figure 48).

The weak linear trends tend to obscure potentially significant regime shifts in water temperatures that were demonstrated in the regional air temperature time-series (Figure 47, bottom). Estimated water temperatures in the Quesnel watershed likely averaged almost 1°C less during 1943-1986, relative to surrounding decades. Water

⁶⁸ Like other multi-day moving air temperature means, the CMAT indicator tends to bias extreme air temperatures towards the mean, thus under-estimating the amplitude and frequency of peak thermal events that may affect fish behaviour. Therefore, this index, and, by extension, any water temperatures estimated as a function of this index, should be treated as a conservative indicator of extreme events. The 7D-CMAT index provided the best trade-off between maximizing correlation and minimizing the effects of multi-day averaging on predictive power at longer period lengths.

⁶⁹ See Appendix J, 1996-2012 for estimated vs observed water temperatures.

temperature changes would be most pronounced in the smaller, more variable, Horsefly system. Inter-annual variation in mean Aug-Sep water temperatures within regimes is high, however, with Quesnel means ranging $\sim 2^{\circ}\text{C}$ in adjacent years (from $14.8\text{--}16.8^{\circ}\text{C}$), and $3\text{--}4^{\circ}\text{C}$ in the lower Horsefly (from $12\text{--}16^{\circ}\text{C}$). Highest temperatures occurred in 2013, when mean Aug-Sep air temperatures exceeded 16°C , and analogous observed water temperatures in the lower Quesnel exceeded 18°C (Table 8).

Review of historical Sockeye daily migration patterns – lagged back to the first 25 km of the lower Quesnel⁷⁰ – in relation to estimated water temperatures indicated little difference in the frequency distribution of dates of migration activity versus the distribution of dates weighted by the amount of fish migrating. Both distributions were approximately normally-distributed around a mode of 16°C . 75% of migration activity occurred between $15\text{--}17^{\circ}\text{C}$, which was also the temperature range of highest daily migration rate (Figure 57 vs Figure 58). In other words, the temperatures associated with the highest daily migration rates overlapped closely with the temperature distribution of available dates, suggesting no real influence of Quesnel water temperature on daily migration patterns. As these temperatures are hospitable to migrating Sockeye, this is not surprising.

Exceedance analyses indicated that the frequency and duration of periods in which conditions would be thermally-stressful to Sockeye migrants (18°C or more) were negligible, affecting perhaps 10% of migration activity. Even temperatures exceeding 18°C occurred less than 7 days per year on average (Figure 68), and persisted for less than a week (Figure 69), with no evident trend over the past seven decades.

However, $\text{POT}_{>18^{\circ}\text{C}}$ periods in the Quesnel may be associated with elevated water temperatures in the Fraser (usually $2\text{--}3^{\circ}\text{C}$ higher than the Quesnel) exerting thermal stress on Horsefly-bound migrants. Known years of Sockeye migration impacts due to elevated temperatures in the Fraser River include: 1992, 1994, 1996–1998, and 2004, 2009, 2013, and 2015 (Patterson et al. 2007; Patterson unpub.). Presumably, these years would be characterized by extended $\text{POT}_{>18^{\circ}\text{C}}$ periods of 10 or more days in the Quesnel system. Only 2004 and 2013 reflected persistent high temperatures, however daily migration data were not available for those years (Appendix J). Spawner arrival timing in 2013 appeared to be ten days later than the multi-year median, but not available in the off-cycle year 2004 (Appendix F; Figure 61).

The lack of daily migration data specific to the Horsefly watershed limited the analysis of Horsefly temperature impacts on the migratory pattern in that sub-system. Of the four years of data available (2005, 2006, 2007, and 2010), only 2006 sustained above-average temperatures into September, with estimated Horsefly

⁷⁰ Based on a presumed swim speed of no more than 25 km/day. Discharge conditions four days prior to Sockeye enumeration in the upper Quesnel (~ 100 km from the Fraser) were statistically pinpointed as having the highest association with variation in daily migration patterns. Swim speeds > 25 km/d would place the site of the statistical association below the mouth of the Quesnel, somewhere in the Fraser River – which is beyond the scope of this analysis.

water temperatures in excess of 17°C, which may have temporarily reduced migration rates (Appendix J). In 2010, a brief, late-August spike in Horsefly water temperature was also coincident with an apparent dip in early migration, but these events did not present notable statistical effects. In 2005, a dominant cycle year, late return timing was indicated by the Horsefly DIDSON counter (despite average Arrival Time recorded in the spawn timing table Appendix F), however, this does not appear to be related to conditions in either the Horsefly or the Quesnel, both of which exhibited average water temperatures (and slightly sub-average discharges) (Appendix J).

While spawner arrival timing (1940-2015) in Horsefly River trended later in the season for dominant and sub-dominant cycle lines, timing was not found to be related to water temperature in either the Quesnel or Horsefly Rivers. This result is in keeping with other studies (e.g. Macdonald et al. 2000) that found little evidence of arrival time delays due to migratory temperature conditions, but did find negative impacts for other indicators (e.g. infection rates, length of time till death, tag mortality/recovery rates, and spawning success), that were related to higher water temperatures on the spawning grounds (Williams 1973a; Cone 1999; MacDonald et al. 2000).

SOCKEYE MIGRATION AND FLOW CONDITIONS

Depending on the temporal window applied, summer discharge in the Quesnel watershed may exhibit weak trends. It is useful to review recent decades versus long-term trends, and to partition the within-season discharge data into migratory and pre-migratory periods.

Discharge In Advance of Migratory Period

Analytically, bundling Aug-Sep flows together while omitting July flows (which precede migration) may obscure hydrological trend impacts on Sockeye migrants.

When the full time-series for the lower Quesnel is partitioned by summer month, neither month in the Aug-Sep migratory period displays any trend. The month of July, however, representing the highest flow levels, shows a weak positive (linear) trend⁷¹ over the same time period (Figure 49)⁷². This may be a function of climate-related reductions in snow-pack depth, rain-on-snow events, and earlier timing of glacier- and snow-melt over recent decades (Kang et al. 2014; Shrestha et al. 2012; Zwiers et al. 2011), resulting in a general decline in Aug-Sep discharge levels punctuated by occasional July floods⁷³ that sometimes persist into August, as the distribution of flows is skewed earlier in the summer season in a warming climate. Despite preceding the migratory period, early summer flows may be more indicative

⁷¹ Though non-parametric analyses do not indicate any trends.

⁷² On a similar note, while the Horsefly demonstrates recent (1960s to present) significant declines in flows in all months (July, August, September), July is declining the least (Figure 50).

⁷³ Historic flood events in the City of Quesnel associated with Quesnel River discharges (30 km upstream) include: 1990: 820 cms for 1 week. 1976: 471 cms for 4 days. 1972: 471 cms for 3 days and 1 week (NHC 1992).

of a developing climatological threat to Sockeye, either directly as semi-regular velocity barriers in Quesnel River, or indirectly through cumulative energetic impacts on spawners exposed to drier, warmer conditions on the Horsefly spawning grounds.

High flow impacts in the Horsefly River were not apparent – discharges probably did not exceed 60 cms (P90) while Sockeye were present, and such flow levels would not overly hinder migrants without the presence of a hydrological 'choke-point'. However, the lack of daily migration data corresponding to high flow years limits our ability to draw any conclusions regarding high discharge effects.

Discharge During Migratory Period

Discharge during the migratory period (Aug-Sep) appears stable over the long-term (i.e. no trend from 1920s to present), but has been declining since the 1960s. Mean Aug-Sep discharge in the lower Horsefly declined by 3 cms per decade since the 1960s, representing a 10% decline in flows over the last 50 years, for a total of ~15 cms (Figure 50, top). Quesnel River mean flows showed no trend since the 1920s, but when truncated to the same time period as the Horsefly, indicated a 12 cms per decade decline (~4% per decade; Figure 49, top).

Despite the downward trend over the past 50 years, some of the highest summer discharge volumes of any year on record have occurred in recent decades, notably in 1982, 1999-2001, and 2011, during which high flows persisted throughout August and into September, potentially delaying or impeding passage of migrants for weeks (e.g. 2001; Appendix J). In some years, high discharge levels persisting into mid-August appear to be coincident with categorical changes to daily migration rates, such as in 1995 and 2001 (Appendix K). Visual and statistical analyses indicated that when high Quesnel flows persisted into the migratory period, moderate-to-high migration rates (> 3% per day) were generally inhibited until daily mean discharge dropped below 350-400 cms, corresponding approximately to the 90th percentile of flows during the migratory period (e.g. 1995, 2001). In other years of high early flows (1999-2000, 2003, 2011), no daily migration data were available.

Low flow impacts, both direct (e.g. drought; obstacles to passage) and indirect (interactions with temperature, disease, reproductive failure) may increasingly materialize in the Horsefly River, where a downward trend in summer discharge was evident over historic time-series (Figure 50). Low flows of 6-8 cms (<P10) were not uncommon (Table 7), at least outside of the artificial spawning grounds. Extreme low flow events (< 4 cms) characterized some of the warmer years, such as 1998 and 2003. High migration rates were not evident in the data below ~8 cms (~10th percentile).

While some of these events may be attributable to the fact that low water levels most typically occurred late in the season, near the end of the Sockeye run, the spawn timing data for dominant and sub-dominant cycle lines indicated that persistently low monthly flows (< 10-12 cms) were consistently associated with later arrival time – and consequently, later spawn activity – on the Horsefly spawning grounds (e.g. 1970, 2002, 2006, 2013; Figure 62 - Figure 65). The declining trend in Horsefly River flows since the 1960s may have contributed to the 'regime shift' to later arrival and peak spawn timing evident in the late 1970s to early 1980s.

The impact on upstream migration of the general decline in Quesnel flows over the past five decades is not clear, based on the data compiled in this study. Quesnel Lake typically maintains more than enough flow for Sockeye migration in the Quesnel River (>100 cms). In fact, the naturalized 7-day summer mean low flow in this system is relatively high, exceeding 25% of the mean annual flow for streams in the Quesnel Highlands, and much higher for the Quesnel and Horsefly Rivers due to their large headwater lakes (Rood and Hamilton 1995).

This may change with expected climate shifts towards warmer, drier summers, which will reinforce the current trends towards lower September flows and higher water temperatures, especially with diminishing supplies of winter snow-pack in the near-future decades, followed by glacial retreat over the long-term (Whitfield 2000; Whitfield and Cannon 2000).

TESTING FOR LOCATION OF ENVIRONMENTAL IMPACTS

The confluence of highest discharge levels in the Quesnel watershed in association with a documented set of rapids providing a potential velocity barrier pointed to Quesnel Canyon in the lower river as a logical place to assess the potential impacts of environmental conditions on the migration pattern of Quesnel Sockeye. But, unlike the situation in the Chilcotin River system, where historic tag studies showed that Farwell Canyon had, at certain discharge levels, delayed or obstructed Chilko Sockeye migration and resulted in fish mortality (IPSFC 1946; in Stiff et al. 2016), no research studies have surfaced that document any impact of high (or low) flows in the Quesnel Canyon system on Sockeye passage. While historical fishery officer records specifically noted a possible obstruction to fish passage at the Big Canyon section of the Quesnel Canyon, Manzon and Marshall (1980) classified this area as "passable". Regrettably, fishery officer annual records were not clarified with associated discharge levels or specific dates.

To probe the data statistically for an environmental signal affecting daily migration patterns, the stratified CMH-GA frequency analysis (p. 22) was employed. Specifically, CMH-GA was used to identify which environmental variate threshold levels were most associated with changes in Sockeye migration rate classification⁷⁴ as enumerated in the upper Quesnel. No assumptions about critical thresholds for temperature or flow levels need be made, but can be arrived at by repeating the statistical test at various combinations of environmental variate threshold levels^{75,76} and examining the CMH-GA test statistics for maximum significance. The environmental threshold levels corresponding to the maximum significance are therefore most influential or associated with categorical changes in the migration rate response variate.

When no date lags are applied (i.e. lag = 0 for migration, temperature and flow data),

⁷⁴ Migration rate class: high or "significant" vs low or "negligible", based on the 50th percentile of daily migration rates from the historical data.

⁷⁵ Lower Quesnel water temperature thresholds tested: integer increments 15-20°C.

⁷⁶ Lower Quesnel discharge thresholds tested: 100-600 cms by increments of 20 cms

the test generates a same-day analysis representative of environmental conditions at the counter sites on the day the fish were being tallied. Merging count data with the previous day's environmental conditions (migration lag = -1 day) and repeating the analysis across all temperature and flow thresholds, tests the association (if any) of conditions one day earlier (i.e. when the fish were still one day downstream of the counter site) on the current day's migration rates⁷⁷. The test was repeated for migration lag = 0 to -7 days (assuming fish could, on average, enter and traverse the entire Quesnel River within one week⁷⁸) for each environmental variate independently (i.e. generating all combinations of flow and MWT over the past week in association with a day of counts).

The results of the CMH-GA analyses indicated a lower Quesnel River "temperature effect" at 17-18°C, at a wide range of discharge levels, on migration counts four days later, with maximum statistical significance below 270 cms and above 340 cms thresholds (Figure 51). Though super-optimal, these temperatures do not surpass the thermal tolerance levels of migrating Sockeye, so this apparent effect may be indicative of prior exposure to more stressful thermal conditions in the Fraser River affecting fish condition, and manifesting as the fish encounter heightened hydrological velocities in the lower Quesnel.

CMH-GA statistics associated with "temperature effects" were less significant than those for "discharge effects". The temperature-stratified distribution in Figure 52 indicated a moving statistical association for migration in relation to discharge across a variable range of lower Quesnel River discharge thresholds, ranging from 280 cms 2-3 days prior to tallying in the upper Quesnel River, to 340-350 cms 4-6 days prior. The moving discharge effect varied with lag time in days, as might be expected given the higher energetic demands on the fish as flow levels increase, which would be expected to slow swim speeds and increase the length of time to reach the upper Quesnel counter site. This posits the existence of a velocity barrier at relatively high flow levels (typically occurring at the beginning of the run) influencing migrant estimates at the counter site 4-6 days later, with similar but reduced effects on migration at lower flow levels 2-3 days later.

As no watershed-specific swim speed studies have been done, uncertainty regarding the swim speed of Sockeye within the Quesnel watershed obscures the location where environmental conditions may be influencing daily migration patterns.

Summer run Sockeye have been found to average 32-52 km/d migrating up the Fraser River (Killick 1955, p. 93; Idler and Clemens 1959, Table 1; Hague, Patterson and Macdonald 2008), but, elsewhere, tag studies generally indicate slower travel rates in the steeper tributary systems. Using a swim speed of 14 km/d (as estimated for Chilko Sockeye moving up the Chilcotin system: IPSFC 1946a), four days' swim

⁷⁷ Under the assumptions of constant swim speed, and discharge and water temperature estimates being applicable "instantaneously" throughout the Quesnel River.

⁷⁸ Godfrey et al (1954) found that Babine Sockeye travel time from above the Babine slide location (20 miles upstream of the Skeena confluence) to the fence (40 miles upstream) was approximately 5 days, indicating a swim speed of 8 miles/day, or 13 km/day.

in the Quesnel would place the location of the corresponding environmental influences 56 km downstream, near Little Canyon, at the upstream end of Quesnel Canyon (Figure 3, Figure 6). Doubling the swim speed (28 km/d) would place the site of environmental influence at the confluence of the Quesnel River and the Fraser. An intermediate swim speed (20-25 km/d) might reasonably implicate high water velocities at Big Canyon, at the downstream end of Quesnel Canyon.⁷⁹

This raises the possibility that Quesnel Canyon may be an important influence on Quesnel Sockeye migration activity. This possibility assumes that the environmental effects are: (a) located within the Quesnel River,⁸⁰ (b) a minimum of 2-3 days to 4-6 days swim time downstream of the Quesnel counter site. Given those assumptions, a lower fish swim speed of ~25 km/d can be derived from partitioning the ~100 km length of the Quesnel into equal parts over four days. This would locate the environmental effects on migration in the lower 25 km of Quesnel River, specifically at Big Canyon (km 14) in the Quesnel Canyon.

The 25 km/d swim speed for Quesnel-bound Sockeye is a departure from some published information indicating a range of 32-52 km/d for Summer-run Sockeye, including Quesnel/Horsefly. However, these estimates were available only for distances in the Fraser River (e.g. Hague et al. 2008), and likely do not apply to the major tributaries like Quesnel River, where hydrological conditions are different (cooler, but steeper) from the Fraser mainstem. Using these swim estimates provide a minimum time length to traverse the Quesnel (~2-3 days), but tag studies in other Fraser tributaries suggest a slower average rate of travel as Sockeye move into their home waters, especially at the front end of the run, when higher flows are most often encountered. Chilko Sockeye tag studies performed in two moderate flow years (1944 and 1945), indicated an average of 13 km/day for Sockeye to traverse the Chilcotin/Chilko leg of their migration (IPSFC 1946a). Elsewhere, tagged Babine Sockeye also averaged 13 km/day from the Babine slide location (upstream of the Skeena confluence) to the Babine Fence (65 km upstream; Godfrey et al. 1954). At 13 km/d, Quesnel Sockeye would take 8 days to traverse the river, and would put the apparent environmental effects about 50 km downstream of the counting site -- where no obstacles are readily apparent. An intermediate swim speed seems reasonable, based on the less strenuous physical conditions found in the Quesnel River relative to the Babine and Chilcotin, especially above Quesnel Forks where the Cariboo River joins the flow.

⁷⁹ This study also found evidence of a downstream discharge effect on fish passage 2-3 days later at the upper Quesnel counter site, potentially indicating swim speeds of ~50 km/d above the canyon, during low-to-moderate discharge levels.

⁸⁰ As opposed to the Fraser River, with which Quesnel conditions are co-variant enough to be statistically-prescriptive. If published swim speeds of 50 km/day for Summer stocks hold true in the Quesnel tributary, then the Fraser/Quesnel confluence would be only two days downstream from the counter sites, and the location of the environmental effects associated with Quesnel migration would be located "two days downstream" of the confluence. However, there being no obvious hydrological mechanism north of Bridge River Rapids (>300 km downstream of Quesnel), the only other mechanism would be a two-day pooling event at the mouth of the Quesnel River.

A similar analysis for Chilko-bound Sockeye identified a strong statistical effect between migration rate and Chilcotin flows 10-12 days earlier – which, at swim speeds empirically-derived from field studies, placed the effect location in the vicinity of the occasionally impassable Farwell Canyon (Stiff et al. 2016). Elsewhere, in the Babine River, categorical changes in Sockeye migration rates at the Babine fence were most significant when lagged 6-7 days earlier in relation to Babine River conditions, and, at documented swim speeds of 13 km/day, approximately coincident with passage through the lower Babine Canyon⁸¹, a place of historic landslides and blocked fish passage (Stiff et al. 2015c). Big Canyon – considered a hydrological challenge for salmon in the Quesnel system (Manzon and Marshall 1980) – provides an analogous mechanism for environmental impacts hindering Quesnel/Horsefly Sockeye Salmon migration that warrants further investigation.

CONCLUSIONS

The goal of the WILD SALMON POLICY (WSP) is "to restore and maintain healthy salmon populations and their habitats for the benefit and enjoyment of the people of Canada in perpetuity" (Fisheries and Oceans Canada 2005). The Sockeye populations in the Quesnel/Horsefly watershed likely represented the largest of all Summer-run timed populations prior to industrial development in the region in the 1880s (Grant et al. 2011). Strong recovery of the population during the 1980s-2000s has been followed by recent significant declines (ibid). As with other Fraser Sockeye stocks, exact reasons for these production declines are elusive but likely associated with human impacts (fisheries, forestry, development) and biological interactions (cyclic dominance, habitat capacity, density dependence (e.g. Koenings and Kyle 1997)) overlaid with the cumulative effects of climate change acting across freshwater and marine life history stages, including adult migration and spawning (Campbell et al. 2014).

Based on the coarse alignment of fish migration data and environmental conditions in this study, it may be concluded that, once the fish have accomplished the Fraser River portion of their upstream journey, high Quesnel River flows extending into the month of August present a potential environmental challenge to migrant Sockeye, possibly in relation to constricted flows at Big Canyon in the lower Quesnel River. The direct and indirect biological impacts of energetically-demanding high-flow reaches in the Quesnel River, resulting in energy-depleting delays, invites further study as climate change projections point to increases in the frequency and duration of high flow events in near-future decades.

While high Quesnel River discharge levels in August have the potential to delay Sockeye migrants, arrival and subsequent spawn timing on the Horsefly spawning grounds were found to be inversely correlated to Horsefly flow levels. Horsefly discharges < 10 cms were associated with later spawn timing, possibly due to

⁸¹ Gradient in the Babine Canyon ~ 9.5% (Godfrey et al. 1954).

reduced access to spawning habitat at low flows combined with higher water temperature.

Long-term average summer water temperatures in both Quesnel and Horsefly watersheds are slowly rising in keeping with regional air temperature changes, but largely remain hospitable to Sockeye migration. Highest mean daily migration rates, and most dates (75%) of migration activity, were both associated with estimated water temperatures of 15-17°C. Temperatures during the Aug-Sep migratory period tend to be consistently warmer, on average, in the Quesnel River ($16 \pm 2^\circ\text{C}$), but more variable in the much smaller Horsefly River ($14 \pm 3^\circ\text{C}$), which is characterized by warmer highs and cooler lows. Above optimum Horsefly water temperatures have been associated with bacterial infection, pre-spawn mortality, and reduced reproductive success in previous studies (e.g. Macdonald et al 2000).

An increase in the frequency and duration of elevated water temperatures, high early summer flow events, and low late summer flow levels is consistent with anticipated climate change in this watershed (Shrestha et al. 2012). This is likely to affect early-timed components of the Horsefly Sockeye run disproportionately, threatening fish productivity and biological diversity. As is the case for other Sockeye stocks, a comprehensive assessment of the cumulative exposure to environmental challenges is increasingly critical to understanding the full impact of freshwater conditions on the health and spawning success of Horsefly Sockeye Salmon (Hague et al. 2008). It is recommended that fisheries authorities comprehensively identify and assess the level of impacts for adaptation response planning (e.g. enhanced harvest management and environmental monitoring to maintain sustainable fisheries) in keeping with WILD SALMON POLICY.

RECOMMENDATIONS

STATISTICAL RE-ANALYSIS

Review and improve statistical analyses between Quesnel/Horsefly Sockeye migration and environmental factors:

- Quesnel-bound salmonids migrate a great distance and are therefore exposed to multiple physical and biological stressors, besides extreme temperatures and flows, affecting enroute survival, including: fisheries, pathogens, predators and pollution. A quantitative multi-variable assessment of the cumulative effects of interacting stressors on fish survival may provide a more realistic representation of the factors influencing migration success.
 - Annual spawner arrival timing (and peak spawn timing) for dominant and sub-dominant cycle lines were inversely correlated with Horsefly discharge, but these results may be confounded by annual spawner abundance and covariance with spawning ground water temperature. Revise model to account for these interactions.
 - Quantile regression (QR) provides a useful extension to regression techniques, by estimating the median response and other quantiles

instead of the mean. Estimating multiple regression quantiles can reveal distinct rates of change between predictor and response variables, therefore providing a more realistic (nonlinear) relationship between fish migration success and ecological stressors or limiting factors (Johnston et al. 2012).

- Geographically-weighted regression methods allow model parameters to vary spatially (Johnson et al. 2012), and could be used to model the effects of stressors by sequential location (e.g. weighting the water temperature effect in the Fraser portion, and weighting high and low discharge effects in the Quesnel and Horsefly portions of the migration route).

ENVIRONMENTAL IMPACT ASSESSMENT - FIELD STUDIES

Re-assess biological impacts of high flow events at Quesnel/Big Canyon in the lower Quesnel, and low flow events in Horsefly River, using current technology:

- Hydrological Surveys: Complete a comprehensive stream survey throughout the canyon area to document the longitudinal channel profile, bank-full channel widths, wetted widths and water velocity at various stage heights to determine the locations of potential velocity barriers at various water levels. The burst swim speed of Sockeye (approximately 2 m/s; Hinch et al. 2002), might serve as a key hydrological threshold for analysis. Rating curves could be developed for each location, and statistically-related to discharge levels at QUESNEL RIVER NEAR QUESNEL for reconstruction of the historic, current, and future time-series under various climate change scenarios. For geologically-unstable sites, specific baseline hydrological indicators are critical to post-slide assessments (Richter et al. 1996).
- Tag Experiments: Employ radio or accelerometer tags on Sockeye migrants in the lower Quesnel downstream of Quesnel/Big Canyon to assess the current level of disruption to migration associated with seasonal and annual hydrology.
 - Bio-Sampling: Develop sampling program to characterize biological condition of Sockeye pre- and post-passage at Quesnel Canyon at various discharge levels to assess impacts on energy reserves and reproductive viability.
- Horsefly River low flows may be delaying fish arrival and reproductive timing on the spawning grounds, which may be exacerbated by projected climate changes for this region (Shrestha et al. 2012). Perform stream surveys to assess causes (e.g. fish passage obstruction) and impacts of delay on fish conditions and reproductive success.

CLIMATE RISK ASSESSMENT

Climate modelling in the Fraser Basin portends temporal and spatial shifts in hydrological regimes, from snow-dominant to hybrid regime in eastern and coastal mountains and from hybrid to rain-dominant regime in the central plateau region (Shrestha et al. 2012). The most significant temporal changes may involve earlier

onsets of snowmelt-driven peak discharge, increased winter and spring runoff and decreased summer runoff, which may be most pronounced in the central plateau region (ibid), potentially exacerbating current trends in the Quesnel/Horsefly watershed.

- Employ climate model downscaling to project future hydrological scenarios at key sites in the watershed (i.e. Quesnel Canyon, Horsefly spawning grounds), incorporating information on temperature, precipitation, groundwater, snow-pack, and ice-melt into the hydrological model (e.g. Shrestha et al. 2012).

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TABLES

QUESNEL A
BRITISH COLUMBIA

Latitude: 53°01'34.000" N Longitude: 122°30'36.000" W Elevation: 545.00 m

1981 to 2010 Canadian Climate Normals station data

	Temperature												Year	Code
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Daily Average (°C)	-6.9	-3.6	1.3	6.4	11.1	14.7	16.8	16.4	11.5	5.5	-1.4	-5.9	5.5	Q
Standard Deviation	4.3	3.8	2.4	1.1	1.6	1.3	1.0	1.0	1.5	1.2	3.5	3.9	2.9	Q
Daily Maximum (°C)	-2.9	1.3	7.3	13.5	18.4	21.7	24.1	24.1	18.5	10.8	2.1	-2.3	11.4	Q
Daily Minimum (°C)	-10.8	-8.3	-4.7	-0.8	3.7	7.6	9.5	8.6	4.5	0.2	-5.0	-9.6	-0.4	Q
Extreme Maximum (°C)	13.9	15.1	22.3	31.0	36.5	35.6	36.7	36.2	36.1	26.8	17.2	12.2		
Date (yyyy/dd)	1968/20	1986/25	1954/29	1977/25	1983/29	1958/24	1961/13	1990/05	1988/04	1987/01	1949/02	1952/13		
Extreme Minimum (°C)	-46.7	-42.2	-38.9	-20.0	-10.0	-3.3	0.6	-2.6	-8.9	-28.4	-37.8	-41.1		
Date (yyyy/dd)	1950/17	1956/15	1955/04	1954/04	1954/01	1955/07	1949/02	1992/23	1951/26	1984/31	1955/26	1958/30		
	Precipitation												Year	Code
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Rainfall (mm)	10.4	6.7	12.7	21.2	41.4	66.4	65.6	46.2	50.2	46.3	22.3	4.9	394.3	Q
Snowfall (cm)	44.0	19.0	13.4	3.6	1.2	0.0	0.0	0.0	0.0	6.7	31.5	42.8	162.1	Q
Precipitation (mm)	47.8	22.7	24.9	24.5	42.6	66.4	65.6	46.2	50.2	52.6	51.3	41.6	536.2	Q
Average Snow Depth (cm)	25	21	9	1	0	0	0	0	0	0	4	14	6	Q
Median Snow Depth (cm)	25	20	8	0	0	0	0	0	0	0	3	13	6	Q
Snow Depth at Month-end (cm)	26	17	2	0	0	0	0	0	0	2	8	21	6	Q
Extreme Daily Rainfall (mm)	26.2	25.4	14.6	34.0	36.8	55.1	30.5	48.3	36.6	35.0	25.4	22.0		
Date (yyyy/dd)	1989/30	1962/02	1993/30	1969/13	1981/25	1955/25	1970/23	1950/23	1984/05	1996/27	1972/01	1980/10		
Extreme Daily Snowfall (cm)	40.1	36.8	24.4	21.6	9.6	0.0	0.0	0.0	4.6	18.8	27.9	36.6		
Date (yyyy/dd)	1958/22	1959/05	1955/05	1966/10	2002/05	1946/01	1946/01	1946/01	1972/28	1967/31	1975/25	1966/06		
Extreme Daily Precipitation (mm)	40.1	36.8	24.4	34.0	36.8	55.1	30.5	48.3	36.6	38.1	27.0	26.2		
Date (yyyy/dd)	1958/22	1959/05	1955/05	1969/13	1981/25	1955/25	1970/23	1950/23	1984/05	1972/31	2004/23	1971/08		

Table 1. QUESNEL Climate Normals (1981-2010). Source: Environment Canada
(http://climate.weather.gc.ca/climate_normals/index_e.html).

StationID	Station Name	Latitude	Longitude	Year Start	Year End	Approx. Elevation (m)	Drainage Area (km ²)	Mean Annual Discharge (cms)	Fish Flow (15% of MAD)
08KH006	QUESNEL RIVER NEAR QUESNEL	52.84	-122.23	1939	2015	470	11,500	240.9	36.1
08KH001	QUESNEL RIVER AT LIKELY	52.62	-121.57	1924	2015	730	5,970	131.1	19.7
08KH031	HORSEFLY RIVER ABOVE QUESNEL LAKE	52.44	-121.42	2004	2015	770		35.8	5.4
08KH019	MOFFAT CREEK NEAR HORSEFLY	52.32	-121.41	1964	2012	780	548	3.4	0.5
08KH010	HORSEFLY RIVER ABOVE MCKINLEY CREEK	52.29	-121.07	1955	2013	840	790	19.5	2.9
08KH020	MCKINLEY CREEK BELOW OUTLET OF MCKINLEY LAKE	52.28	-121.00	2011	2014	950	431	5.0	0.8

Table 2. Hydrometric station data from the Quesnel watershed (Source: ECCC WSC HYDAT database).

	LikelyBridge										
	Date			Sockeye Migrants			Migration Rate (%)				
	Date Count	Min Date	Max Date	Mean Daily	Max Daily	Annual Total	P50	P75	P95	Mean Daily	Max Daily
Year											
1993	52	13AUG	03OCT	445	2,370	23,125	0.65	2.54	9.33	1.92	10.25
1994	48	15AUG	01OCT	128	434	6,139	1.14	3.16	6.76	2.08	7.06
1995	29	21AUG	18SEP	55	213	1,585	0.54	6.59	13.00	3.45	13.46
1997	62	08AUG	09OCT	469	2,986	29,100	0.65	1.58	8.22	1.61	10.26
1998	57	05AUG	30SEP	99	550	5,627	0.92	2.74	6.60	1.75	9.77
2001	62	05AUG	06OCT	502	2,096	31,133	1.06	2.23	5.10	1.61	6.73
1993-2001	310	13AUG	06OCT	312	2,986	96,709	0.73	2.69	7.58	1.94	13.46

Table 3. Annual migration statistics for Sockeye daily migrants visually-counted from Likely Bridge, Quesnel River. Filtered for non-zero daily counts for migration period, mean and maximum daily average migrant count, annual total counts, and daily migration rate (%) statistics.

	Quesnel										
	Date			Sockeye Migrants			Migration Rate (%)				
	Date Count	Min Date	Max Date	Mean Daily	Max Daily	Annual Total	P50	P75	P95	Mean Daily	Max Daily
Year											
2009	60	08AUG	06OCT	2,626	8,262	157,541	1.50	2.76	4.35	1.67	5.24
2010	52	08AUG	28SEP	5,176	15,278	269,142	1.47	2.73	4.65	1.92	5.68
2014	52	14AUG	04OCT	15,852	45,066	824,309	1.75	3.68	4.47	1.92	5.47
2015	48	13AUG	29SEP	898	1,980	43,124	1.73	2.96	4.17	2.08	4.59
2009, 2010, 2014, 2015	212	08AUG	29SEP	6,104	45,066	1,294,116	1.61	2.98	4.35	1.89	5.68

	Horsefly										
	Date			Sockeye Migrants			Migration Rate (%)				
	Date Count	Min Date	Max Date	Mean Daily	Max Daily	Annual Total	P50	P75	P95	Mean Daily	Max Daily
Year											
2005	65	06AUG	09OCT	9,928	64,488	645,310	0.56	2.09	5.55	1.54	9.99
2006	54	09AUG	01OCT	1,614	5,645	87,167	1.63	3.10	5.08	1.85	6.48
2007	44	13AUG	25SEP	1,381	6,974	60,763	1.37	3.69	7.42	2.27	11.48
2010	50	14AUG	02OCT	3,043	12,333	152,167	1.56	3.05	5.75	2.00	8.10
2005, 2006, 2007, 2010	213	06AUG	02OCT	4,439	64,488	945,407	1.12	2.84	6.35	1.88	11.48

Table 4. Annual migration statistics for Sockeye daily migrants acoustically-counted by DIDSON arrays from Quesnel River (2009-2010, 2014-2015) and Horsefly River (2005-2007, 2010). Total daily counts are filtered for non-zero daily totals for migration period, mean and maximum daily average migrant count, annual total counts, and daily migration rate (%) statistics.

QUESNEL RIVER NEAR QUESNEL,
08KH006,
Discharge (m³/s)

	Discharge (cms)						Percentiles						
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P90	P95
Year													
1993	61	107.0	194.0	273.0	48.9	-0.5	109.0	114.0	159.0	207.0	231.0	248.0	258.0
1994	61	140.0	214.1	390.0	69.4	1.1	142.0	147.0	165.0	179.0	245.0	336.0	353.0
1995	61	154.0	298.2	449.0	96.4	-0.1	157.0	166.0	212.0	289.0	397.0	409.0	416.0
1996	61	212.0	333.6	498.0	69.7	0.3	218.0	237.0	296.0	321.0	384.0	428.0	457.0
1997	61	185.0	291.0	519.0	96.1	0.9	188.0	197.0	208.0	280.0	343.0	448.0	476.0
1998	61	98.6	172.9	284.0	54.0	0.4	105.0	107.0	124.0	163.0	216.0	257.0	268.0
1999	61	198.0	365.1	682.0	136.6	0.7	210.0	212.0	257.0	330.0	455.0	584.0	600.0
2000	61	232.0	354.4	649.0	98.5	1.7	251.0	282.0	300.0	323.0	352.0	508.0	601.0
2001	61	189.0	349.3	629.0	131.9	0.5	193.0	195.0	222.0	337.0	422.0	566.0	587.0
2002	61	177.0	242.4	413.0	57.1	1.4	180.0	186.0	211.0	221.0	259.0	335.0	363.0
2003	61	119.0	167.8	243.0	37.8	0.5	123.0	126.0	134.0	153.0	202.0	222.0	234.0
2004	61	193.0	294.6	433.0	77.0	0.3	203.0	208.0	219.0	269.0	356.0	399.0	416.0
2005	61	143.0	216.9	364.0	61.4	0.9	151.0	158.0	163.0	205.0	243.0	314.0	348.0
2006	61	111.0	172.5	298.0	55.2	0.8	113.0	113.0	126.0	158.0	210.0	255.0	276.0
2007	61	133.0	197.3	359.0	57.5	1.1	136.0	137.0	157.0	176.0	219.0	289.0	314.0
2008	61	165.0	265.5	361.0	56.7	-0.4	176.0	183.0	212.0	288.0	306.0	327.0	342.0
2009	61	147.0	213.3	358.0	54.5	1.2	162.0	164.0	175.0	188.0	243.0	299.0	329.0
2010	61	140.0	183.7	258.0	35.0	0.8	144.0	152.0	159.0	167.0	208.0	243.0	248.0
2011	61	183.0	320.7	624.0	122.5	1.0	192.0	202.0	217.0	299.0	388.0	508.0	576.0
2012	61	133.0	265.7	479.0	100.7	0.6	141.0	148.0	187.0	237.0	338.0	419.0	446.0
2013	61	149.0	206.2	281.0	37.8	0.4	154.0	163.0	176.0	197.0	236.0	267.0	271.0
2014	61	165.0	254.4	412.0	68.6	0.5	167.0	170.0	186.0	248.0	294.0	356.0	387.0
2015	61	146.0	196.8	271.0	37.4	0.3	153.0	156.0	162.0	185.0	234.0	245.0	250.0
All	1403	98.6	250.9	682.0	99.6	1.3	136.0	151.0	177.0	225.0	302.0	388.0	438.0

QUESNEL RIVER NEAR QUESNEL,
08KH006,
Discharge (m³/s)

	Discharge (cms)						Percentiles						
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P90	P95
Year													
All	4697	97.4	263.7	786.0	97.8	1.1	140.0	156.0	187.0	247.0	318.0	388.0	447.0

Table 5. Discharge statistics for observed WSC station data from the lower QUESNEL RIVER NEAR QUESNEL, during the peak adult Sockeye migration period, August-September 1993-2015 (top), summary statistics 1939-2015 (bottom).

HORSEFLY RIVER ABOVE QUESNEL LAKE,
08KH031,
Discharge (m³/s)

	Discharge (cms)						Percentiles						
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P90	P95
Year													
2004	23	34.8	47.6	57.6	6.0	-0.5	36.8	38.9	43.2	48.2	51.4	54.2	55.5
2005	61	8.5	14.1	29.6	5.1	1.7	9.3	10.3	11.0	12.4	14.4	21.9	25.9
2006	61	5.3	9.7	19.0	3.7	0.8	5.7	5.8	6.3	9.2	11.9	15.3	17.3
2007	0												
2008	30	19.6	27.8	43.1	6.0	0.7	19.9	20.3	23.0	26.9	32.5	36.4	37.8
2009	61	7.3	11.3	19.8	3.1	0.9	7.6	8.1	8.9	10.5	13.2	16.2	17.1
2010	61	8.0	14.3	28.4	5.1	1.2	8.5	9.1	11.1	12.9	15.0	22.4	24.5
2011	61	13.8	25.1	60.3	11.6	1.3	14.0	14.6	16.1	20.7	31.4	42.6	48.8
2012	61	8.2	17.2	38.8	8.7	1.1	8.6	9.0	10.7	13.1	22.8	30.9	35.7
2013	61	8.7	12.7	17.6	2.3	0.5	9.2	10.0	11.2	12.2	13.8	16.3	17.1
2014	61	8.1	15.3	34.3	6.4	1.3	8.4	8.8	10.9	13.4	18.1	25.1	29.2
2015	61	6.0	10.0	24.5	4.4	1.9	6.1	6.5	7.5	8.6	9.7	17.2	19.3
All	602	5.3	16.3	60.3	10.2	1.9	7.0	8.2	10.0	12.8	18.8	29.5	38.8

Table 6. Observed discharge statistics for WSC station data from the lower HORSEFLY RIVER ABOVE QUESNEL LAKE, during the peak adult Sockeye migration period, August-September 2004-2015.

Horsefly River above Quesnel Lake

Year	Daily Mean						Percentiles						
	Dates	Min	Mean	Max	Std	Skew	P5	P10	P25	P50	P75	P90	P95
1981	61	14.9	23.3	42.3	7.8	1.1	15.2	15.6	17.0	21.0	27.3	37.3	41.4
1982	61	32.0	56.3	95.4	18.1	0.6	34.3	37.3	40.3	53.5	68.2	85.3	87.6
1983	61	14.0	22.2	48.2	8.2	1.4	14.6	15.5	16.8	18.5	26.5	33.9	37.9
1984	61	18.4	32.1	54.0	8.6	0.5	20.8	21.3	24.8	30.8	37.9	42.8	48.2
1985	61	6.8	12.4	19.5	3.3	0.1	7.5	7.9	9.8	12.0	15.1	16.5	17.1
1986	61	5.5	13.5	29.8	7.0	1.0	5.7	6.3	8.2	11.4	16.7	24.9	27.7
1987	61	3.5	10.8	28.2	6.5	0.9	3.9	4.1	5.3	9.1	14.6	19.9	25.0
1988	61	6.0	12.8	21.7	4.6	0.3	6.6	7.1	8.9	13.2	15.2	19.9	21.4
1989	61	12.8	22.1	42.0	6.2	1.1	15.0	15.3	17.6	21.3	25.9	28.4	35.0
1990	61	7.6	9.8	19.2	2.4	2.3	7.9	8.1	8.5	9.0	9.7	12.8	15.6
1991	61	12.4	24.0	43.7	7.6	0.8	13.7	15.3	18.9	22.7	27.8	33.9	39.4
1992	61	6.0	12.1	27.6	5.8	1.1	6.3	6.4	7.4	9.7	14.2	21.7	23.9
1993	61	11.6	18.5	31.8	5.4	0.8	12.0	12.2	14.3	17.0	22.8	25.4	29.6
1994	61	10.1	13.0	17.1	2.1	0.6	10.2	10.5	11.4	12.9	14.0	16.7	17.0
1995	61	14.0	39.9	70.5	18.9	0.1	14.3	15.4	21.9	38.7	55.1	66.9	68.4
1996	61	18.1	27.0	39.7	5.7	0.3	18.5	19.3	23.0	26.0	30.9	36.1	36.6
1997	61	14.9	25.3	56.4	9.7	1.7	17.0	17.7	19.7	21.5	27.0	42.2	46.3
1998	61	4.9	9.3	20.6	3.9	1.0	5.1	5.3	6.0	9.0	11.5	14.3	17.5
1999	61	18.4	30.4	55.4	10.4	0.8	19.1	20.0	22.3	27.4	38.2	46.3	48.7
2000	61	14.5	23.1	52.6	8.4	1.6	14.8	15.3	16.7	20.8	26.2	34.9	40.6
2001	61	13.3	30.3	89.7	19.4	1.6	13.6	14.2	16.6	24.3	35.2	61.9	76.1
2002	61	10.2	13.9	21.4	3.0	1.0	10.8	10.9	11.6	13.0	15.5	18.8	20.5
2003	61	2.9	6.9	10.4	1.8	-0.1	4.2	4.7	5.5	6.9	8.3	9.1	9.4
2004	61	7.8	29.2	57.6	18.1	0.1	8.5	9.4	11.0	32.3	47.5	50.8	53.0
2005	61	8.5	14.1	29.6	5.1	1.7	9.3	10.3	11.0	12.4	14.4	21.9	25.9
2006	61	5.3	9.7	19.0	3.7	0.8	5.7	5.8	6.3	9.2	11.9	15.3	17.3
2007	61	7.3	10.7	17.5	2.6	1.1	7.7	7.8	8.9	9.9	11.7	14.8	16.0
2008	61	15.9	24.3	43.1	6.3	0.8	16.6	17.1	19.6	23.3	28.1	33.1	35.1
2009	61	7.2	11.3	19.8	3.1	0.9	7.6	8.1	8.9	10.5	13.2	16.2	17.1
2010	61	8.0	14.3	28.4	5.1	1.2	8.5	9.1	11.1	12.9	15.0	22.4	24.5
2011	61	13.8	25.1	60.3	11.6	1.3	14.0	14.6	16.1	20.7	31.4	42.6	48.8
2012	61	8.2	17.2	38.8	8.7	1.3	8.5	9.0	10.7	13.1	22.8	30.9	35.7
2013	61	8.7	12.7	17.6	2.3	0.5	9.2	9.9	11.2	12.2	13.8	16.3	17.1
2014	61	8.1	15.3	34.3	6.4	1.3	8.4	8.8	10.9	13.4	18.1	25.1	29.2
2015	61	5.9	10.0	24.5	4.4	1.9	6.0	6.5	7.5	8.6	9.7	17.2	19.3
All	3955	2.9	22.2	161.7	16.6	2.6	6.4	8.2	11.4	17.2	27.8	41.8	52.0

Table 7. Observed and estimated discharge statistics for the lower Horsefly River, Aug-Sep 1955-2015. Missing data based on statistical relations with upper Horsefly and McKinley Creek discharge data. (Years: 1955-1980 not shown)

Quesnel (WSC) Water Temperature Statistics (Aug-Sep)

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
2000	45	9.18	13.77	16.47	1.83	-0.35	12.5	13.7	15.3	16.4
2001	51	11.89	15.30	17.49	1.28	-0.84	14.5	15.6	16.1	17.1
2003	61	12.12	16.17	19.37	2.19	-0.46	14.2	16.7	17.7	19.1
2004	61	11.13	15.75	20.18	2.74	-0.05	13.2	16.0	17.9	19.8
2005	59	11.67	15.01	17.46	1.57	-0.45	13.8	15.3	16.2	17.2
2006	61	11.24	15.68	17.64	1.62	-1.02	14.5	16.4	16.9	17.3
2007	61	10.77	14.96	17.16	1.67	-0.79	13.8	15.5	16.3	16.9
2008	61	10.33	15.45	18.74	2.23	-0.31	14.0	15.6	17.5	18.4
2009	61	12.63	16.51	18.64	1.40	-1.06	15.9	16.7	17.5	18.2
2010	61	12.15	15.44	18.45	1.93	-0.14	14.1	15.5	17.2	18.4
2011	50	12.09	14.29	16.69	1.29	0.15	13.4	14.1	15.6	16.4
2012	61	12.40	15.64	19.08	1.80	0.28	14.3	15.5	16.9	18.7
2013	61	13.10	18.19	23.68	2.57	-0.22	17.1	18.3	19.5	22.4
2014	61	10.68	15.55	19.34	2.05	-0.32	14.1	15.7	17.2	18.4
2015	61	12.29	15.04	18.94	1.97	-0.26	13.8	15.9	17.5	18.6
All	876	9.18	15.62	23.68	2.14	0.09	14.0	15.8	17.2	18.8

Table 8. Statistical summary of observed and estimated daily water temperature data for QUESNEL RIVER (NEAR QUESNEL) during Sockeye migration (August-September) (Source: 2000-2001, 2003-2012: DFO ENVIRONMENTAL WATCH PROGRAM; 2013-2015 ECCC WATER SURVEY OF CANADA). All statistics are derived from daily mean temperatures from *N* annual dates. For example, *Min* and *Max* are the minimum and maximum of the daily mean temperature estimates, and therefore are not the observed extremes.

Horsefly (HR22) Water Temperature Statistics (Aug-Sep)

	Water Temperature						Percentiles			
	Dates	Min	Mean	Max	Std	Skew	P25	P50	P75	P95
Year										
1995	61	9.60	12.94	15.50	1.41	-0.66	12.2	13.2	13.9	14.7
1996	60	6.70	12.91	17.20	2.96	-0.38	11.0	13.2	15.6	17.0
1997	61	9.00	14.58	18.90	2.62	-0.41	12.3	15.1	16.6	18.4
1998	61	9.70	15.66	20.70	2.99	-0.21	13.1	15.0	17.6	20.1
1999	61	6.45	13.65	17.81	2.97	-0.61	11.8	13.5	16.3	17.5
2000	61	7.51	13.11	18.44	3.18	0.08	10.3	12.6	16.1	17.9
2001	61	9.05	13.95	18.51	2.14	0.14	12.9	13.8	15.3	18.2
2002	60	8.23	13.44	19.16	2.93	0.15	10.8	13.5	15.4	18.6
2003	25	13.86	18.18	20.52	1.64	-1.08	17.3	18.6	19.4	20.1
2004	61	8.00	14.18	20.99	4.14	0.32	10.4	13.7	18.1	20.7
2005	61	7.52	13.81	18.57	3.32	-0.28	11.5	13.7	16.7	18.1
2006	35	8.70	14.90	17.77	2.79	-1.00	12.1	16.3	16.8	17.6
2007	61	5.91	13.47	18.72	3.37	-0.56	10.5	14.2	16.0	17.6
2008	61	8.67	13.10	18.60	2.63	0.48	11.4	12.6	14.4	17.9
2009	61	8.12	15.44	21.64	3.07	-0.26	13.1	15.6	17.8	20.3
2010	45	9.97	15.13	19.46	3.07	0.03	12.6	14.2	18.2	19.4
2011	0									
2012	61	10.18	14.44	19.41	2.80	0.13	11.8	14.5	16.9	18.8
All	957	5.91	14.11	21.64	3.10	-0.06	11.8	14.0	16.6	19.0
All	897	5.91	13.97	21.64	3.06	-0.01	11.8	13.9	16.3	18.9

Table 9. Statistical summary of observed and estimated daily water temperature data for HORSEFLY RIVER during Sockeye migration (August-September) (Source: Site HR-22; DFO ENVIRONMENTAL WATCH PROGRAM). Final total row omits incomplete years 2003, 2006, and 2011 from summary statistics. All statistics are derived from daily mean temperatures from *N* annual dates. For example, *Min* and *Max* are the minimum and maximum of the daily mean temperature estimates, and therefore are not the observed extremes.

Fraser River at Qualark

Decade	Year	Water Temperature					Percentiles			
		Dates	Min	Mean	Max	Std	P25	P50	P75	P95
1940s	1941	10	17.0	18.8	21.0	1.6	18.0	18.0	20.5	21.0
	1942	62	15.5	17.9	19.5	1.1	17.5	18.0	19.0	19.5
	1943	63	12.0	14.6	17.3	1.4	13.7	14.5	16.0	16.5
	1944	52	12.0	16.6	19.5	1.8	15.5	17.0	18.0	19.0
	1945	59	14.3	16.9	19.1	1.2	16.1	16.7	17.7	18.9
	1946	9								
	1947	72	13.5	15.7	17.5	1.0	15.0	16.0	16.5	17.0
	1948	27	14.0	16.5	18.3	0.9	15.7	16.5	17.1	17.9
	1949	0								
	All	345	12.0	16.4	21.0	1.7	15.4	16.5	17.5	19.0
1950s	1950	49	13.9	16.2	18.6	1.2	15.4	16.4	17.2	18.1
	1951	92	9.7	15.2	17.8	2.2	13.9	15.5	17.2	17.8
	1952	53	12.8	15.9	19.2	1.6	15.0	15.8	16.4	18.9
	1953	92	10.8	15.4	18.1	1.5	14.7	15.6	16.1	17.8
	1954	92	10.7	14.8	17.4	1.4	13.9	14.9	15.6	16.9
	1955	92	10.7	14.8	16.8	1.5	14.2	15.3	16.0	16.4
	1956	77	11.8	16.5	19.7	1.9	15.7	16.7	17.9	19.4
	1957	92	12.7	15.3	17.2	1.1	14.9	15.4	16.1	16.9
	1958	91	10.6	17.1	20.0	2.5	15.6	18.3	18.9	19.4
	1959	92	11.3	14.5	17.5	1.7	13.1	15.1	16.0	16.8
	All	822	9.7	15.5	20.0	1.9	14.4	15.6	16.7	18.6
1960s	1960	92	11.0	14.8	19.1	2.1	13.2	14.4	15.9	18.6
	1961	92	9.7	16.7	20.0	2.7	14.5	18.1	18.6	19.7
	1962	91	12.4	14.9	17.8	1.6	13.3	14.4	16.1	17.8
	1963	92	13.9	16.3	19.2	1.4	15.6	16.1	17.2	18.9
	1964	92	10.4	14.2	16.1	1.4	12.9	14.4	15.4	16.0
	1965	91	11.1	15.7	19.2	2.2	13.9	16.1	17.8	18.6
	1966	92	12.2	15.2	17.2	1.2	14.4	15.5	16.1	16.9
	1967	91	12.8	16.2	19.2	1.7	15.0	16.1	17.5	18.9
	1968	92	9.9	14.4	18.1	1.8	13.8	14.7	15.6	16.9
	1969	92	11.7	15.2	18.6	1.8	14.2	15.3	16.8	17.8
	All	917	9.7	15.4	20.0	2.0	14.1	15.4	16.7	18.6
1970s	1970	92	10.0	15.7	18.9	2.5	13.9	16.7	17.4	18.6
	1971	92	10.6	15.6	19.4	2.6	13.0	16.0	17.8	19.4
	1972	91	8.9	15.4	18.9	2.4	13.9	16.1	17.2	18.3
	1973	60	12.8	15.4	18.9	2.0	13.9	15.6	17.0	18.9
	1974	87	12.2	14.7	17.2	1.5	13.3	14.4	16.1	16.7
	All									

Fraser River at Qualark

Decade	Year	Water Temperature					Percentiles			
		Dates	Min	Mean	Max	Std	P25	P50	P75	P95
1970s	1975	92	12.8	15.5	17.8	1.3	14.4	15.6	16.7	17.2
	1976	86	12.8	14.9	17.2	1.2	13.9	15.0	15.6	16.7
	1977	92	11.7	15.6	19.4	2.0	14.0	15.3	17.2	18.9
	1978	92	11.7	16.2	19.4	2.2	15.0	16.7	17.8	18.9
	1979	91	13.3	16.7	18.9	1.7	15.6	17.2	18.3	18.9
	All	875	8.9	15.6	19.4	2.1	13.9	15.6	17.2	18.9
1980s	1980	92	11.7	15.4	18.3	1.7	13.9	15.6	16.7	17.8
	1981	92	12.8	16.8	20.0	1.9	15.3	17.2	18.3	20.0
	1982	92	11.7	15.3	18.3	1.7	14.2	15.6	16.1	17.8
	1983	89	10.0	15.8	19.4	2.1	14.4	16.1	17.2	18.3
	1984	88	8.9	14.7	18.1	2.3	13.0	14.6	17.2	17.8
	1985	91	10.0	15.4	18.9	2.4	13.5	16.1	17.2	18.3
	1986	88	12.2	15.8	18.1	1.8	14.8	16.4	17.3	18.0
	1987	90	13.3	16.4	18.3	1.3	15.6	16.7	17.2	18.3
	1988	92	11.8	16.4	18.5	1.9	15.1	17.4	17.8	18.2
	1989	92	14.6	16.7	18.2	1.0	16.0	16.9	17.6	18.0
	All	906	8.9	15.9	20.0	2.0	14.5	16.1	17.2	18.3
1990s	1990	92	13.5	16.5	19.3	1.5	15.8	16.3	17.9	19.0
	1991	92	14.1	16.6	19.2	1.3	15.6	16.5	17.8	18.9
	1992	92	11.0	17.1	20.5	2.9	14.9	17.6	19.5	20.3
	1993	92	13.0	16.8	19.6	1.7	16.0	17.2	18.2	19.3
	1994	92	13.7	17.3	20.0	1.8	15.7	17.7	19.0	19.7
	1995	92	13.8	16.6	19.1	1.2	16.1	16.7	17.3	18.5
	1996	92	12.0	15.5	18.4	1.6	14.4	15.6	16.9	17.9
	1997	92	13.7	16.1	18.2	1.3	15.0	16.4	17.3	18.0
	1998	92	14.4	18.3	21.2	1.8	17.4	18.6	19.4	21.0
	1999	92	11.8	15.2	18.3	1.7	13.9	15.1	16.8	18.0
	All	920	11.0	16.6	21.2	1.9	15.4	16.7	18.0	19.7
2000s	2000	92	11.8	15.5	19.1	2.0	13.8	15.6	17.3	18.5
	2001	92	13.8	16.3	19.3	1.1	15.4	16.4	16.8	18.7
	2002	91	11.7	15.8	19.3	2.0	14.5	16.3	17.2	18.7
	2003	92	12.5	17.1	20.2	2.2	15.5	17.5	18.9	20.0
	2004	92	12.1	17.4	21.5	2.8	15.3	18.0	19.8	21.2
	2005	92	12.3	16.3	19.3	1.8	15.6	16.5	17.8	18.7
	2006	92	13.5	17.6	20.7	1.7	17.2	18.0	18.6	20.0
	2007	87	13.9	16.4	18.2	1.2	15.5	16.8	17.4	17.7
	2008	92	12.7	16.2	19.3	1.7	14.8	16.2	17.7	18.9
	2009	92	12.8	17.4	21.0	1.8	16.3	17.5	18.8	20.7
	All	914	11.7	16.6	21.5	2.0	15.3	16.8	18.0	19.8
2010s	2010	92	12.4	16.5	19.1	1.9	15.0	16.5	18.4	19.0
	2011	92	11.9	15.3	17.6	1.5	14.4	15.6	16.6	17.3
	2012	0								
	All	184	11.9	15.9	19.1	1.8	14.8	16.0	17.1	18.9
	All	5883	8.9	16.0	21.5	2.0	14.6	16.1	17.4	19.0
All		3888	8.9	15.9	21.5	2.1	14.4	16.1	17.6	19.0

Table 10. Statistical summary of observed and estimated daily water temperature data for FRASER RIVER AT QUALARK during Sockeye migration (July-September N=5,883; August-September N=3,888) (Source: DFO ENVIRONMENTAL WATCH PROGRAM). All statistics are derived from daily mean temperatures from N annual dates. For example, MIN and MAX are the minimum and maximum of the daily mean temperature estimates, and therefore are not the observed extremes.

----- Site=Quesnel -----

	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
2000			60	54
2001	93	53		
2002			63	11
2003			73	65
2004	92	70		
2005			80	61
2006			81	70
2007	121	70		
2008	121	70		
2009	120	70		
2010	121	70		
2011			120	59
2012	121	70		
2013	77	70		
2014	121	70		
2015	121	70		

Table 11. Number of annual water temperature observations available for air/water temperature analyses for QUESNEL AHCCD / QUESNEL RIVER, partitioned into warming and cooling seasons at August 2nd for seasonal relationships. Air/water temperature model calibration data years were selected based on maximum correlation between seasonal air/water time-series and maximum range of temperature observations.

Quesnel Air/Water Logistic (Intercept) Model - All Seasons 2000-2015 - Calibration					
Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	4	281335	70333.7	9222.94	<.0001
Error	1787	13627.6	7.6259		
Uncorrected Total	1791	294962			
Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		
alpha	20.8895	1.3649	18.2125	23.5665	
beta	9.9526	0.7324	8.5161	11.3891	
gamma	0.1596	0.0266	0.1073	0.2118	
nu	-1.9706	2.0289	-5.9499	2.0087	

Quesnel Air/Water Logistic (Intercept) Model - Warming Season 2000-2015 - Calibration					
Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	3	16131.6	5377.2	1851.38	<.0001
Error	1104	3206.5	2.9044		
Corrected Total	1107	19338.0			
Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		
alpha	18.2466	0.6291	17.0122	19.4811	
beta	13.3626	0.2800	12.8132	13.9121	
gamma	0.2588	0.0208	0.2179	0.2996	
nu	2.5066	0.3596	1.8010	3.2121	

Quesnel Air/Water Logistic (Intercept) Model - Cooling Season 2000-2015 - Calibration					
Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F
Model	4	167826	41956.5	28839.5	<.0001
Error	679	987.8	1.4548		
Uncorrected Total	683	168814			
Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		
alpha	25.8885	7.6970	10.7757	41.0012	
beta	10.3037	6.0355	-1.5467	22.1541	
gamma	0.0939	0.0811	-0.0653	0.2531	
nu	1.0544	13.9897	-26.4140	28.5227	

Quesnel - Logistic (Intercept) Model - Nash-Sutcliffe Coefficient 2000-2015 - Calibration						
Goodness of Fit for Season Data & Hysteresis Check against NSC for All Data						
Obs	Season Numerator	Season Denominator	NSC Season Data	NSC All Data	NSC Season - NSC All	Result
1	4194.30	23234.83	0.81948	0.63231	0.18717	Hysteresis detected

Table 12. Logistic regression output for air/water temperature relationship between the QUESNEL 7d-CMAT (air temperature index) and calibration data for lower QUESNEL RIVER daily mean water temperatures: seasons combined (top); warming season (middle); cooling season (bottom). Hysteresis was detected ($NSC_{seasonal} - NSC_{all} = 0.19$).

Quesnel - Air/Water Temperature (Based on Quesnel_7dMAT/WaterT REG Model)							
Calibration Years - 2000-2015 - Warming Season							
Analysis of Variance							
Source		DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model		1	15712	15712	4791.81	<.0001	
Error		1106	3626.40359	3.27885			
Corrected Total		1107	19338				
	Root MSE		1.81076	R-Square	0.8125		
	Dependent Mean		9.81831	Adj R-Sq	0.8123		
	Coeff Var		18.44267				
Parameter Estimates							
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t	95% Confidence Limits
Intercept	Intercept	1	0.01455	0.15171	0.10	0.9236	-0.28313 0.31223
Quesnel_7dMAT	7d-MAT	1	0.78613	0.01136	69.22	<.0001	0.76384 0.80841
Calibration Years - 2000-2015 - Cooling Season							
Analysis of Variance							
Source		DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model		1	2906.56144	2906.56144	1998.87	<.0001	
Error		681	990.24480	1.45410			
Corrected Total		682	3896.80624				
	Root MSE		1.20586	R-Square	0.7459		
	Dependent Mean		15.53898	Adj R-Sq	0.7455		
	Coeff Var		7.76024				
Parameter Estimates							
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t	95% Confidence Limits
Intercept	Intercept	1	7.75600	0.18049	43.07	<.0001	7.40239 8.10960
Quesnel_7dMAT	7d-MAT	1	0.55649	0.01245	44.71	<.0001	0.53206 0.58093
Check TYPE III SS for SEASON significance, if P<.05 intercepts are different & hysteresis exists							
Source		DF	Type III SS	Mean Square	F Value	Pr > F	
Quesnel_7dMAT		1	18256.72081	18256.72081	6557.31	<.0001	
Season		1	8788.35991	8788.35991	3156.54	<.0001	
Check TYPE III SS for interaction term significance, if P<.05, slopes are different & hysteresis exists							
Source		DF	Type III SS	Mean Square	F Value	Pr > F	
Quesnel_7dMAT		1	3909.946161	3909.946161	1513.45	<.0001	
Season		1	2043.665753	2043.665753	791.06	<.0001	
Quesnel_7dMAT*Season		1	361.462791	361.462791	139.91	<.0001	

Table 13. Linear regression output for air/water temperature relationship between the QUESNEL 7d-CMAT (air temperature index) and calibration data for the lower QUESNEL RIVER daily mean water temperatures: warming season (top); cooling season (middle). Type III sum of squares for season effect (test for equal intercepts) and for season interaction effect (test for equal slopes) were both highly significant ($P < 0.0001$), indicating hysteresis.

---- Site=Quesnel Dataset=Validation Season=Warming ----		
Pearson Correlation Coefficients, N = 477		
Prob > r under H0: Rho=0		
	Logistic Model Water Temp	Linear Model Water Temp
WaterT	0.80166	0.80073
Daily MWT	<.0001	<.0001
---- Site=Quesnel Dataset=Validation Season=Cooling ----		
Pearson Correlation Coefficients, N = 320		
Prob > r under H0: Rho=0		
	Logistic Model Water Temp	Linear Model Water Temp
WaterT	0.82713	0.82593
Daily MWT	<.0001	<.0001

Table 14. Comparison of Pearson correlation coefficients for observed (WaterT) versus estimated lower QUESNEL RIVER daily mean water temperature (from logistic and linear models) for validation data years: warming season (top); cooling season (bottom).

		Air Temp						Water Temp (Modeled)					Water Temp (Obs'd + Est'd)					
		N	Min	P10	Med	P95	Max	Min	P10	Med	P95	Max	N	Min	P10	Med	P95	Max
Decade	Month																	
1900s	8	310	5.1	11.1	14.2	17.5	25.0	12.5	14.3	15.6	16.8	18.3	0					
	9	300	1.7	6.2	10.3	14.4	18.1	9.3	11.6	13.4	15.0	16.9	0					
	All	610	1.7	7.3	12.3	16.6	25.0	9.3	12.3	14.5	16.4	18.3	0					
1910s	Month																	
	8	310	5.6	12.5	16.4	20.3	24.2	13.6	15.4	16.8	18.1	19.3	0					
	9	300	1.7	7.5	12.0	15.8	21.4	10.8	12.3	14.3	16.1	17.8	0					
	All	610	1.7	8.9	14.2	19.2	24.2	10.8	13.1	15.9	17.8	19.3	0					
1920s	Month																	
	8	310	8.6	12.5	17.0	20.6	26.7	13.4	15.5	17.2	18.5	19.3	0					
	9	300	-2.0	6.8	12.3	16.8	19.8	9.3	12.3	14.4	16.4	17.5	0					
	All	610	-2.0	8.9	14.8	19.5	26.7	9.3	13.2	16.0	17.9	19.3	0					
1930s	Month																	
	8	310	7.0	12.7	16.4	20.3	23.3	14.0	15.4	16.9	18.2	19.2	0					
	9	300	0.0	6.8	11.6	17.3	22.5	10.1	12.1	14.1	16.9	18.1	0					
	All	610	0.0	8.4	14.7	19.5	23.3	10.1	12.9	16.1	17.8	19.2	0					
1940s	8	310	7.5	12.3	15.6	19.7	23.9	13.6	15.2	16.4	18.2	19.1	0					
	9	300	2.8	7.1	12.0	16.4	19.5	10.6	12.4	14.4	16.5	17.3	0					
	All	610	2.8	8.6	14.2	18.7	23.9	10.6	13.2	15.5	17.6	19.1	0					
1950s	Month																	
	8	310	8.1	11.7	15.0	18.7	21.1	13.5	14.6	16.1	17.7	18.9	0					
	9	300	-1.4	6.3	12.0	16.0	19.2	9.7	11.7	14.4	16.1	16.8	0					
	All	610	-1.4	8.3	13.9	18.0	21.1	9.7	12.6	15.4	17.2	18.9	0					
1960s	Month																	
	8	310	7.8	11.9	15.9	19.9	22.3	13.8	14.9	16.4	18.4	19.0	0					
	9	300	0.3	7.4	11.4	15.6	21.7	9.8	12.2	14.3	15.7	17.9	0					
	All	610	0.3	8.8	13.7	19.2	22.3	9.8	12.9	15.3	17.9	19.0	0					
1970s	Month																	
	8	310	6.1	12.2	16.0	20.2	23.6	13.3	14.8	16.6	18.3	19.3	0					
	9	300	-0.6	7.0	11.4	15.1	20.5	9.1	12.1	14.3	15.8	17.2	0					
	All	610	-0.6	8.4	13.6	18.9	23.6	9.1	12.7	15.3	17.9	19.3	0					
1980s	8	310	9.4	12.9	15.9	20.0	24.0	14.0	15.3	16.6	18.2	19.6	0					
	9	300	1.8	6.6	11.6	15.7	22.8	9.8	11.8	14.2	16.2	17.9	0					
	All	610	1.8	8.0	14.2	19.1	24.0	9.8	12.6	15.7	17.7	19.6	0					
1990s	Month																	
	8	310	9.1	12.8	16.4	20.7	24.6	14.0	15.3	16.9	18.5	19.6	0					
	9	300	3.6	7.4	12.4	16.4	21.6	10.8	12.4	14.6	16.2	17.2	0					
	All	610	3.6	8.9	14.5	19.4	24.6	10.8	13.2	15.8	17.9	19.6	0					
2000s	Month																	
	8	496	7.8	12.4	16.2	20.3	23.7	11.7	15.4	16.7	18.3	19.4	448	12.1	14.9	16.9	18.7	23.7
	9	480	1.9	7.2	11.8	16.7	21.3	11.3	12.5	14.2	16.2	17.8	432	9.2	12.2	14.1	16.6	18.8
	All	976	1.9	8.8	14.1	19.2	23.7	11.3	13.0	15.7	17.8	19.4	880	9.2	12.7	15.8	18.2	23.7
Total		7076	-2.0	8.4	13.9	18.9	26.7	9.1	12.8	15.6	17.7	19.6	880	9.2	12.7	15.8	18.2	23.7

Table 15. Statistics for August-September regional mean air temperature (QUESNEL AHCCD), and lower QUESNEL RIVER modeled water temperature (1900-2012), and observed (or linearly estimated) Quesnel River water temperature, 2000-2015.

		Air Temp						Water Temp (Modeled)					Water Temp (Obs'd + Est'd)					
		N	Min	P10	Med	P95	Max	Min	P10	Med	P95	Max	N	Min	P10	Med	P95	Max
Decade	Month																	
1900s	8	310	5.1	11.1	14.2	17.5	25.0	8.8	12.0	14.3	16.5	19.0	0					
	9	300	1.7	6.2	10.3	14.4	18.1	4.3	7.4	10.3	13.1	16.5	0					
	All	610	1.7	7.3	12.3	16.6	25.0	4.3	8.5	12.3	15.7	19.0	0					
1910s	Month																	
	8	310	5.6	12.5	16.4	20.3	24.2	10.7	14.0	16.3	18.7	20.4	0					
	9	300	1.7	7.5	12.0	15.8	21.4	6.2	8.5	11.9	15.0	18.1	0					
	All	610	1.7	8.9	14.2	19.2	24.2	6.2	9.7	14.8	18.0	20.4	0					
1920s	Month																	
	8	310	8.6	12.5	17.0	20.6	26.7	11.1	14.2	17.1	19.2	20.4	0					
	9	300	-2.0	6.8	12.3	16.8	19.8	4.3	8.4	12.1	15.6	17.6	0					
	All	610	-2.0	8.9	14.8	19.5	26.7	4.3	10.0	14.9	18.3	20.4	0					
1930s	Month																	
	8	310	7.0	12.7	16.4	20.3	23.3	12.1	14.0	16.6	18.7	20.3	0					
	9	300	0.0	6.8	11.6	17.3	22.5	5.2	8.1	11.6	16.5	18.6	0					
	All	610	0.0	8.4	14.7	19.5	23.3	5.2	9.4	15.2	18.0	20.3	0					
1940s	8	310	7.5	12.3	15.6	19.7	23.9	10.8	13.6	15.7	18.7	20.1	0					
	9	300	2.8	7.1	12.0	16.4	19.5	6.0	8.7	12.0	15.7	17.2	0					
	All	610	2.8	8.6	14.2	18.7	23.9	6.0	9.9	14.1	17.6	20.1	0					
1950s	Month																	
	8	310	8.1	11.7	15.0	18.7	21.1	10.4	12.9	15.1	17.9	19.8	0					
	9	300	-1.4	6.3	12.0	16.0	19.2	4.7	7.5	12.1	15.0	16.3	0					
	All	610	-1.4	8.3	13.9	18.0	21.1	4.7	9.0	13.8	17.1	19.8	0					
1960s	Month																	
	8	310	7.8	11.9	15.9	19.9	22.3	11.0	13.0	15.6	19.0	20.0	0					
	9	300	0.3	7.4	11.4	15.6	21.7	4.8	8.4	11.8	14.4	18.2	0					
	All	610	0.3	8.8	13.7	19.2	22.3	4.8	9.4	13.7	18.2	20.0	0					
1970s	Month																	
	8	310	6.1	12.2	16.0	20.2	23.6	10.2	12.8	16.1	18.9	20.4	0					
	9	300	-0.6	7.0	11.4	15.1	20.5	4.0	8.1	11.8	14.5	17.0	0					
	All	610	-0.6	8.4	13.6	18.9	23.6	4.0	9.1	13.7	18.2	20.4	0					
1980s	8	310	9.4	12.9	15.9	20.0	24.0	11.4	13.7	16.2	18.7	20.9	0					
	9	300	1.8	6.6	11.6	15.7	22.8	4.9	7.7	11.7	15.2	18.2	0					
	All	610	1.8	8.0	14.2	19.1	24.0	4.9	8.9	14.4	17.9	20.9	0					
1990s	Month																	
	8	310	9.1	12.8	16.4	20.7	24.6	12.0	13.6	16.6	19.2	20.8	155	11.9	13.2	16.0	18.4	20.7
	9	300	3.6	7.4	12.4	16.4	21.6	6.2	8.7	12.4	15.3	17.0	149	6.4	9.1	11.9	14.9	16.1
	All	610	3.6	8.9	14.5	19.4	24.6	6.2	10.0	14.6	18.2	20.8	304	6.4	10.5	13.9	17.4	20.7
2000s	Month																	
	8	496	7.8	12.4	16.2	20.3	23.7	9.8	13.8	16.2	18.9	20.6	360	10.8	13.9	16.5	19.0	21.6
	9	480	1.9	7.2	11.8	16.7	21.3	6.9	8.7	11.7	15.2	18.0	293	5.9	8.8	11.4	13.7	20.3
	All	976	1.9	8.8	14.1	19.2	23.7	6.9	9.6	14.4	18.0	20.6	653	5.9	9.9	14.1	18.4	21.6
Total		7076	-2.0	8.4	13.9	18.9	26.7	4.0	9.4	14.2	17.9	20.9	957	5.9	10.1	14.0	18.2	21.6

Table 16. Statistics for August-September regional mean air temperature (QUESNEL AHCCD), and lower HORSEFLY RIVER modeled water temperature (1900-2012), and observed (or linearly estimated) Horsefly River water temperature, 1995-2015.

----- Site=Horsefly -----

	Calibration		Validation	
	Warming	Cooling	Warming	Cooling
	Observations	Observations	Observations	Observations
Year				
1995			80	70
1996			121	63
1997			75	70
1998	121	69		
1999			77	70
2000			121	66
2001	93	70		
2002	77	69		
2003			121	27
2004	54	70		
2005			121	70
2006	121	43		
2007	121	70		
2008			44	70
2009	119	70		
2010	121	47		
2011			0	0
2012	121	70		

Table 17. Number of annual water temperature observations available for QUESNEL / HORSEFLY RIVER air/water temperature analyses, partitioned into warming and cooling seasons at August 2nd for seasonal relationships.

Horsefly Air/Water Logistic (Intercept) Model - All Seasons 1995-2012 - Calibration						
Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F	
Model	4	245037	61259.4	17857.1	<.0001	
Error	1501	5149.2	3.4305			
Uncorrected Total	1505	250187				
Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness	Label
alpha	25.0000	0	25.0000	25.0000	.	
beta	13.9022	0.3371	13.2409	14.5634	-0.3082	
gamma	0.1678	0.00623	0.1555	0.1800	0.0439	
mu	0.0647	0.6302	-1.1714	1.3008	-0.2958	
Bound0	5.7661	2.0486	1.7516	9.7807	.	alpha <= 25

Horsefly Air/Water Logistic (Intercept) Model - Warming Season 1995-2012 - Calibration						
Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F	
Model	4	127467	31866.6	13277.3	<.0001	
Error	923	2215.3	2.4001			
Uncorrected Total	927	129682				
Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness	Label
alpha	25.0000	0	25.0000	25.0000	.	
beta	15.9321	0.1879	15.5633	16.3009	-0.2432	
gamma	0.1953	0.00692	0.1817	0.2089	0.0435	
mu	2.0430	0.3705	1.3158	2.7702	-0.2260	
Bound0	5.8330	1.3601	3.1679	8.4982	.	alpha <= 25

Horsefly Air/Water Logistic (Intercept) Model - Cooling Season 1995-2012 - Calibration						
Source	DF	Sum of Squares	Mean Square	F Value	Approx Pr > F	
Model	3	7176.3	2392.1	1708.83	<.0001	
Error	574	803.5	1.3998			
Corrected Total	577	7979.8				
Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits		Skewness	
alpha	25.8348	2.1524	21.6074	30.0623	1.5316	
beta	12.5562	0.6548	11.2701	13.8423	-0.9151	
gamma	0.1574	0.0318	0.0949	0.2199	-0.3491	
mu	-0.4082	2.7170	-5.7447	4.9283	-1.6668	

Goodness of Fit for Season Data & Hysteresis Check against NSC for All Data						
Obs	Season Numerator	Season Denominator	NSC Season Data	NSC All Data	NSC Season - NSC All	Result
1	3018.78	26520.21	0.08617	0.02681	0.059364	Hysteresis detected

Table 18. Logistic regression output for air/water temperature relationship between the QUESNEL 7d-CMAT (air temperature index) and calibration data for HORSEFLY RIVER daily mean water temperatures: seasons combined (top); warming season (middle); cooling season (bottom). Hysteresis was detected ($NSC_{seasonal} - NSC_{all} = 0.06$).

Horsefly Air/Water Linear Model - Warming Season 1995-2012 - Calibration							
Analysis of Variance							
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F		
Model	1	16065	16065	6002.44	<.0001		
Error	925	2475.64940	2.67638				
Corrected Total	926	18540					
	Root MSE	Mean	1.63596	R-Square	0.8665		
	Dependent	10.94959		Adj R-Sq	0.8663		
	Coeff Var	14.94086					
Parameter Estimates							
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t	95% Confidence Limits
Intercept	Intercept	1	-0.98795	0.16318	-6.05	<.0001	-1.30870 -0.66770
Quesnel_7DMAT	7d-RAT	1	0.91157	0.01177	77.48	<.0001	0.88848 0.93466

Horsefly Air/Water Linear Model - Cooling Season 1995-2012 - Calibration							
Analysis of Variance							
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F		
Model	1	7162.08694	7162.08694	5045.21	<.0001		
Error	576	817.57921	1.41958				
Corrected Total	577	7979.66615					
	Root MSE	Mean	1.19146	R-Square	0.8975		
	Dependent	13.95278		Adj R-Sq	0.8974		
	Coeff Var	8.53924					
Parameter Estimates							
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t	95% Confidence Limits
Intercept	Intercept	1	0.59948	0.19442	3.08	0.0021	0.21763 0.98134
Quesnel_7DMAT	7d-RAT	1	0.96539	0.01359	71.03	<.0001	0.93878 0.99209

TYPE III SS for interaction term significance - if P<.05, slopes are different (hysteresis)						
Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Quesnel_7DMAT	1	2182.998259	2182.998259	994.94	<.0001	
Season	1	68.895822	68.895822	31.40	<.0001	
Quesnel_7DMAT*Season	1	15.928777	15.928777	7.26	0.0071	

TYPE III SS for SEASON significance - if P<.05, intercepts are different (hysteresis)						
Source	DF	Type III SS	Mean Square	F Value	Pr > F	
Quesnel_7DMAT	1	23210.94930	23210.94930	10534.9	<.0001	
Season	1	1903.62432	1903.62432	864.01	<.0001	

Table 19. Linear regression output for air/water temperature relationship between the QUESNEL 7d-CMAT (air temperature index) and calibration data for HORSEFLY RIVER daily mean water temperatures: warming season (top); cooling season (middle). Type III sum of squares for season interaction effect (test for equal slopes) and season effect (test for equal intercepts) was highly significant (bottom), indicating hysteresis.

---- Site-Horsefly Dataset-Validation Season=Warming ----

Pearson Correlation Coefficients, N = 757
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT	0.91859	0.91031
Daily MMT	<.0001	<.0001

---- Site-Horsefly Dataset-Validation Season=Cooling ----

Pearson Correlation Coefficients, N = 506
Prob > |r| under H0: Rho=0

	Logistic Model Water Temp	Linear Model Water Temp
WaterT	0.92541	0.92473
Daily MMT	<.0001	<.0001

Table 20. Comparison of Pearson correlation coefficients for observed (WaterT) versus estimated (from logistic and linear models) HORSEFLY RIVER daily mean water temperature for validation data years: warming season (top); cooling season (bottom).

Stock-Horsefly Parameters=17c 0d 270cms 0d MigLoHiLag 3.0% 5.0% -4d

Table 1 of MutClass by MigClass
Controlling for FlowClass=FLOW<270cmsMutClass(Mean Daily Water Temperature)
MigClass(Daily Migration Class)

Frequency Row Pct Col Pct	MIG<5.0%	MIG>5.0%	Total
MWT<17c	51 65.38 75.00	27 34.62 93.10	78
MWT>17c	17 89.47 25.00	2 10.53 6.90	19
Total	68	29	97

Table 2 of MutClass by MigClass
Controlling for FlowClass=FLOW>270cmsMutClass(Mean Daily Water Temperature)
MigClass(Daily Migration Class)

Frequency Row Pct Col Pct	MIG<5.0%	MIG>5.0%	Total
MWT<17c	0 34.78 100.00	15 65.22 100.00	23
MWT>17c	0 0.00	0 0.00	0
Total	0	15	23

Summary Statistics for MutClass by MigClass
Controlling for FlowClass

Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	4.1865	0.0407
2	Row Mean Scores Differ	1	4.1865	0.0407
3	General Association	1	4.1865	0.0407

Stock-Horsefly Parameters=17c 0d 380cms 0d MigLoHiLag 3.0% 5.0% -4d

Table 1 of MutClass by MigClass
Controlling for FlowClass=FLOW<380cmsMutClass(Mean Daily Water Temperature)
MigClass(Daily Migration Class)

Frequency Row Pct Col Pct	MIG<5.0%	MIG>5.0%	Total
MWT<17c	59 61.46 77.63	37 38.54 94.87	96
MWT>17c	17 89.47 22.37	2 10.53 5.13	19
Total	76	39	115

Table 2 of MutClass by MigClass
Controlling for FlowClass=FLOW>380cmsMutClass(Mean Daily Water Temperature)
MigClass(Daily Migration Class)

Frequency Row Pct Col Pct	MIG<5.0%	MIG>5.0%	Total
MWT<17c	0 0.00 -	5 100.00 100.00	5
MWT>17c	0 -	0 0.00	0
Total	0	5	5

Summary Statistics for MutClass by MigClass
Controlling for FlowClass

Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	5.5061	0.0190
2	Row Mean Scores Differ	1	5.5061	0.0190
3	General Association	1	5.5061	0.0190

Table 21. Contingency tables based on categorization of dates of high/low daily migration rates (5% threshold) as a function of lower Quesnel River water temperature category (17°C threshold), stratified by flow category (270 cms threshold, top; 380 cms threshold, bottom). Large differences in the frequency distribution of Sockeye migration dates ($P < 0.05$) indicates association of migration level with environmental conditions occurring 4 days before Sockeye reached the Quesnel River counter site.

Stock-Horsefly Parameters-17c 6d 300cms 6d High/Low Lag 3.0% 5.0% -3d

Table 1 of FlowClass by MigClass
Controlling for RetClass=RM17cFlowClass(Mean Daily Flow (m3/s))
MigClass(Daily Migration Class)

Frequency Row Pct Col Pct	MIG<5.0%	MIG>5.0%	Total
FLOW<300cms	58 69.08 93.55	25 30.12 62.50	83
FLOW>300cms	4 21.05 6.45	15 78.95 37.50	19
Total	62	40	102

Table 2 of FlowClass by MigClass
Controlling for RetClass=RM17cFlowClass(Mean Daily Flow (m3/s))
MigClass(Daily Migration Class)

Frequency Row Pct Col Pct	MIG<5.0%	MIG>5.0%	Total
FLOW<300cms	14 77.78 100.00	4 22.22 100.00	18
FLOW>300cms	0 0.00	0 0.00	0
Total	14	4	18

Summary Statistics for FlowClass by MigClass
Controlling for RetClass

Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	15.3116	<.0001
2	Row Mean Scores Differ	1	15.3116	<.0001
3	General Association	1	15.3116	<.0001

Stock-Horsefly Parameters-17c 6d 340cms 6d High/Low Lag 3.0% 5.0% -5d

Table 1 of FlowClass by MigClass
Controlling for RetClass=RM17cFlowClass(Mean Daily Flow (m3/s))
MigClass(Daily Migration Class)

Frequency Row Pct Col Pct	MIG<5.0%	MIG>5.0%	Total
FLOW<340cms	59 67.82 98.33	28 32.18 68.29	87
FLOW>340cms	1 7.14 1.67	13 92.86 31.71	14
Total	60	41	101

Table 2 of FlowClass by MigClass
Controlling for RetClass=RM17cFlowClass(Mean Daily Flow (m3/s))
MigClass(Daily Migration Class)

Frequency Row Pct Col Pct	MIG<5.0%	MIG>5.0%	Total
FLOW<340cms	16 84.21 100.00	3 15.79 100.00	19
FLOW>340cms	0 0.00	0 0.00	0
Total	16	3	19

Summary Statistics for FlowClass by MigClass
Controlling for RetClass

Cochran-Mantel-Haenszel Statistics (Based on Table Scores)

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	18.2266	<.0001
2	Row Mean Scores Differ	1	18.2266	<.0001
3	General Association	1	18.2266	<.0001

Table 22. Contingency tables based on categorization of dates of high/low daily migration rates (5% threshold) as a function of lower Quesnel River discharge category (at 300 cms threshold, 3 days earlier, top; 340 cms threshold, 5 days earlier, bottom), stratified by water temperature category (17°C threshold). Large differences in the frequency distribution of Sockeye migration dates ($P < 0.001$) indicates migration levels appear to be associated with environmental conditions varying 3-6 days before Sockeye reached the Quesnel River counter site.

	Spawner Per cent	Arrival Time	Peak Spawner Timing	Peak Spawner Time		Spawner Per cent	Arrival Time	Peak Spawner Timing	Peak Spawner Time
Year					Year				
1940	010P1940	245	110P1940	255	1982				
1941	150001941	227	270001941	239	1983			000P1983	249
1942					1984			000P1984	250
1943					1985	100001985	222	110P1985	254
1944					1986			100P1986	254
1945	140001945	226	070P1945	250	1987			100P1987	254
1946	150001946	227	000001946	242	1988	110001988	224	000P1988	252
1947					1989			100P1989	253
1948					1990	150001990	227	050P1990	248
1949	000001949	229	030P1949	246	1991				
1950	200001950	235	200001950	238	1992				
1951	200001951	232	250001951	238	1993	200001993	232	200P1993	263
1952	120001952	225	000001952	243	1994	150001994	227	100P1994	253
1953	040001953	216	200001953	240	1995	150001995	227	000P1995	252
1954	200001954	235	030P1954	246	1996				
1955	210001955	233	050P1955	248	1997	140001997	226	150P1997	258
1956	100001956	231	310001956	244	1998	170001998	229	120P1998	255
1957	050001957	217	030P1957	246	1999			050P1999	248
1958	150001958	227	000P1958	251	2000			050P2000	249
1959					2001	100002001	231		
1960	100001960	232	110P1960	255	2002	250002002	237		
1961	050001961	217	200001961	241	2003	250002003	237	100P2003	253
1962	200001962	235	010P1962	244	2004			000P2004	253
1963	120001963	224	270001963	239	2005	150002005	227	170P2005	260
1964	250001964	238	110P1964	255	2006	210002006	233	070P2006	250
1965	060001965	218	310001965	243	2007	250002007	237	100P2007	253
1966	150001966	227	040P1966	247	2008			070P2008	251
1967	140001967	226	030P1967	246	2009	150002009	227	110P2009	254
1968	200001968	233	050P1968	249	2010	140002010	226	150P2010	258
1969	070001969	219	000001969	242	2011	250002011	237	110P2011	254
1970	200001970	236	050P1970	248	2012			100P2012	254
1971			310001971	243	2013	250002013	237	120P2013	255
1972	200001972	233	070P1972	251	2014	150002014	227	120P2014	255
1973	140001973	226	310001973	243	2015	100002015	230	140P2015	257
1974			000P1974	251					
1975			000P1975	251					
1976	070P1976	251	170P1976	261					
1977	050001977	221	040P1977	247					
1978	200001978	232	070P1978	250					
1979			100P1979	250					
1980			100P1980	254					
1981	110001981	223	000001981	242					

(Cont. round)

Table 23. Horsely Sockeye spawn timing, including annual dates of Arrival and Peak Spawn activity, and associated Julian dates, 1940-2015. (Note: inter-annual comparisons across all cycle lines are not appropriate given large differences in annual spawning ground survey efforts.)

08KH010 August Flows			08KH010 September Flows		
The CORR Procedure			The CORR Procedure		
Pearson Correlation Coefficients Prob > r under H0: Rho=0 Number of Observations			Pearson Correlation Coefficients Prob > r under H0: Rho=0 Number of Observations		
	Arrival JulDate	PeakJul Date		Arrival JulDate	PeakJul Date
AugP10Flow Value	-0.61628 0.0023 22	-0.42275 0.0353 25	SepP10Flow Value	-0.45859 0.0318 22	-0.37260 0.0666 25
AugP25Flow Value	-0.63034 0.0017 22	-0.42663 0.0334 25	SepP25Flow Value	-0.51193 0.0149 22	-0.39363 0.0516 25
AugMeanFlow Value	-0.57298 0.0053 22	-0.45908 0.0210 25	SepMeanFlow Value	-0.56072 0.0066 22	-0.41617 0.0385 25
AugP50Flow Value	-0.60413 0.0029 22	-0.49897 0.0111 25	SepP50Flow Value	-0.55162 0.0078 22	-0.38571 0.0569 25
AugP60Flow Value	-0.57793 0.0048 22	-0.49823 0.0113 25	SepP60Flow Value	-0.54089 0.0093 22	-0.36420 0.0735 25
AugP70Flow Value	-0.57346 0.0053 22	-0.45426 0.0225 25	SepP70Flow Value	-0.55302 0.0076 22	-0.41378 0.0398 25
AugP75Flow Value	-0.53300 0.0106 22	-0.44058 0.0275 25	SepP75Flow Value	-0.56040 0.0067 22	-0.44678 0.0252 25
AugP80Flow Value	-0.51720 0.0137 22	-0.45373 0.0227 25	SepP80Flow Value	-0.57014 0.0056 22	-0.46225 0.0200 25
AugP90Flow Value	-0.45062 0.0353 22	-0.41398 0.0397 25	SepP90Flow Value	-0.59090 0.0038 22	-0.43709 0.0289 25
AugMaxFlow Value	-0.43525 0.0429 22	-0.39091 0.0533 25	SepMaxFlow Value	-0.59143 0.0037 22	-0.40732 0.0433 25

Table 24. Pearson correlation coefficients for observed adult Sockeye annual Arrival Timing (Julian date) and Peak Spawn Timing (Julian date) as a function of quantiles of Horsefly River monthly flow level, dominant/sub-dominant cycle lines only, by month, 1940-2015. Highlighted values indicate significant correlations ($P < 0.05$).

Annual Frequency & Mean Duration (days) for POT20c Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1900s	3	1	1.3	2	0.6
1910s	22	1	1.8	11	2.1
1920s	29	1	1.5	4	0.8
1930s	20	1	2.2	5	1.3
1940s	17	1	1.6	4	0.9
1950s	5	1	1.8	4	1.3
1960s	16	1	2.0	6	1.4
1970s	18	1	2.1	4	1.1
1980s	21	1	1.8	6	1.2
1990s	25	1	2.0	6	1.6
2000s	27	1	2.4	6	1.7
Total	203	1	1.9	11	1.4

Annual Frequency & Mean Duration (days) for POT20c Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1900s	3	1	1.3	2	0.6
1910s	22	1	1.8	11	2.1
1920s	29	1	1.5	4	0.8
1930s	20	1	2.2	5	1.3
1940s	17	1	1.6	4	0.9
1950s	5	1	1.8	4	1.3
1960s	16	1	2.0	6	1.4
1970s	18	1	2.1	4	1.1
1980s	21	1	1.8	6	1.2
1990s	25	1	2.0	6	1.6
2000s	27	1	2.4	6	1.7
Total	203	1	1.9	11	1.4

Table 25. Frequency analysis of decadal mean number of dates per month in which regional daily mean air temperature at QUESNEL weather station exceeded 20°C (top); min., mean and max. length (days) and total frequency of periods in which regional daily mean air temperature continuously exceeded 20°C (August-September), by decade (bottom).

Quesnel - Decadal Mean Monthly MMT Peaks > 18c

Site: Quesnel River

	Years in Decade	Mean No. Days		Mean Annual Total
		Aug	Sep	
Decade				
1900s	10	0.2		0.2
1910s	10	4.9		4.9
1920s	10	5.6		5.6
1930s	10	4.1	0.2	4.3
1940s	10	4.5		4.5
1950s	10	1.5		1.5
1960s	10	5.9		5.9
1970s	10	5.7		5.7
1980s	10	4.9		4.9
1990s	10	6.1		6.1
2000s	16	4.8		4.8

Quesnel - Annual Frequency & Mean Duration (days) for PDT18c Events

	PDT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1900s	1	2	2.0	2	
1910s	11	1	4.5	17	4.7
1920s	10	1	5.1	12	4.7
1930s	9	1	4.6	11	3.5
1940s	6	1	7.2	15	5.1
1950s	2	3	7.0	11	5.7
1960s	10	2	5.8	13	3.8
1970s	10	1	5.6	12	4.2
1980s	8	1	6.0	19	6.0
1990s	9	1	6.7	19	6.2
2000s	16	1	4.6	15	3.6
Total	92	1	5.4	19	4.4

Table 26. Frequency analysis of decadal mean number of dates per month in which estimated mean water temperature in the lower Quesnel River exceeded 18°C (top); min., mean and max. length (days) and total frequency of periods in which estimated mean water temperature continuously exceeded 18°C (August-September), by decade (bottom).

Quesnel - Annual Frequency & Mean Duration (days) for POT18c Events

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1980s	1984	1	6	6.0	6	
	1985	1	1	1.0	1	
	1986	2	1	2.5	4	2.1
	1987	0				
	1988	1	2	2.0		
	1989	1	7	7.0	7	
	Total	8	1	5.5	19	5.9
1990s	Year					
	1990	1	16	16.0	16	
	1991	1	15	15.0	15	
	1992	2	4	4.5	5	0.7
	1993	0				
	1994	0				
	1995	0				
	1996	1	1	1.0	1	
	1997	0				
	1998	2	2	4.0	6	2.8
	1999	1	5	5.0	5	
	Total	8	1	6.8	16	5.7

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
2000s	2000	1	2	2.0	2	
	2001	1	4	4.0	4	
	2002	1	4	4.0	4	
	2003	1	2	2.0	2	
	2004	1	9	9.0	9	
	2005	0				
	2006	0				
	2007	0				
	2008	1	5	5.0	5	
	2009	3	1	1.3	2	0.6
	2010	1	3	3.0	3	
	2011	0				
	2012	2	4	4.5	5	0.7
	2013	1	14	14.0	14	
	2014	2	1	4.0	7	4.2
	2015	0				
	Total	15	1	4.3	14	3.5
Total		88	1	5.1	19	4.5

(Continued)

Table 27. Min., mean and max. length (days) and total frequency of periods in which estimated mean water temperature in the lower Quesnel River continuously exceeded 18°C (August-September), by year (only recent decades shown).

Horsefly - Decadal Mean Monthly MMT Peaks > 18c

Site: Horsefly River

	Years in Decade	Mean No. Days		Mean Annual Total
		Aug	Sep	
Decade				
1900s	10	0.2		0.2
1910s	10	6.1	0.2	6.3
1920s	10	8.2		8.2
1930s	10	5.7	0.6	6.3
1940s	10	5.2		5.2
1950s	10	2.8		2.8
1960s	10	6.9	0.4	7.3
1970s	10	7.2		7.2
1980s	10	5.8	0.2	6.0
1990s	10	7.4		7.4
2000s	16	6.4	0.1	6.6

Horsefly - Annual Frequency & Mean Duration (days) for POT18c Events

	POT Event Duration (days)				
	N	Min	Avg	Max	Std
Decade					
1900s	1	2	2.0	2	
1910s	11	1	5.6	22	6.1
1920s	13	1	6.2	19	6.2
1930s	11	1	5.5	13	3.8
1940s	6	1	8.5	16	6.5
1950s	6	1	4.5	10	4.3
1960s	11	1	6.5	15	4.3
1970s	11	1	6.5	17	5.7
1980s	12	1	4.9	20	5.2
1990s	14	1	5.1	18	5.6
2000s	20	1	5.2	16	3.8
Total	116	1	5.7	22	5.0

Table 28. Frequency analysis of decadal mean number of dates per month in which estimated mean water temperature in the lower Horsefly River exceeded 18°C (top); min., mean and max. length (days) and total frequency of periods in which estimated mean water temperature continuously exceeded 18°C (August-September), by decade (bottom).

Horsefly - Annual Frequency & Mean Duration (days) for POT18c Events

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
1980s	1984	1	7	7.0	7	
	1985	1	2	2.0	2	
	1986	3	1	2.3	4	1.5
	1987	0				
	1988	2	2	3.0	4	1.4
	1989	3	2	4.0	8	3.5
	Total	12	1	4.9	20	5.2
1990s	Year					
	1990	1	18	18.0	18	
	1991	1	17	17.0	17	
	1992	2	5	5.5	6	0.7
	1993	1	2	2.0	2	
	1994	3	1	1.3	2	0.6
	1995	0				
	1996	1	2	2.0	2	
	1997	2	1	1.5	2	0.7
	1998	2	3	5.0	7	2.8
	1999	1	5	5.0	5	
	Total	14	1	5.1	18	5.6

		POT Event Duration (days)				
		N	Min	Avg	Max	Std
Decade	Year					
2000s	2000	2	1	2.0	3	1.4
	2001	1	6	6.0	6	
	2002	1	4	4.0	4	
	2003	3	1	3.0	6	2.6
	2004	1	11	11.0	11	
	2005	0				
	2006	0				
	2007	0				
	2008	1	7	7.0	7	
	2009	2	2	3.5	5	2.1
	2010	2	3	5.5	8	3.5
	2011	0				
	2012	2	5	6.0	7	1.4
	2013	2	2	9.0	16	9.9
	2014	2	5	6.5	8	2.1
	2015	1	1	1.0	1	
	Total	20	1	5.2	16	3.8
Total		116	1	5.7	22	5.0

(Continued)

Table 29. Min., mean and max. length (days) and total frequency of periods in which estimated mean water temperature in the lower Horsefly River continuously exceeded 18°C (August-September), by year (only recent decades shown).

Horsefly River Water Flow Exceedance Analysis
Based on Horsefly River Obs+Est Discharge

Monthly and Annual No. Dates < 8 cms

Decade	Year	Freq POT8 cms Dates		Total Days
		Aug	Sep	
1970s	1970	16	10	26
	1971			
	1972			
	1973		10	10
	1974			
	1975			
	1976			
	1977			
	1978			
	1979	5	29	34
1980s	1980			
	1981			
	1982			
	1983			
	1984			
	1985	4	3	7
	1986	1	13	14
	1987		26	26
	1988		13	13
	1989			
1990s	1990	5		5
	1991			
	1992	11	7	18
	1993			
	1994			
	1995			
	1996			
	1997			
	1998		27	27
	1999			

Decade	Year	Freq POT8 cms Dates		Total Days
		Aug	Sep	
2000s	2000			
	2001			
	2002			
	2003	18	21	39
	2004	2		2
	2005			
	2006	5	21	26
	2007		7	7
	2008			
	2009	4	2	6
	2010			
	2011			
	2012			
	2013			
	2014			
	2015	17	6	23

(Continued)

Table 30. Annual total frequency of dates per month (August-September) in which observed or estimated discharge in the lower HORSEFLY RIVER was less than 8 cms.

Decade	Year	POT Event Duration (days)							
		N	Min	Avg	Max	Std	P10	MED	P90
1960s	1967	2	7	12.5	18	7.8	7.0	12.5	18.0
	Total	2	7	12.5	18	7.8	7.0	12.5	18.0
1970s	Year								
	1970	2	5	12.5	20	10.6	5.0	12.5	20.0
	1973	1	10	10.0	10		10.0	10.0	10.0
	1979	2	12	16.5	21	6.4	12.0	16.5	21.0
	Total	5	5	13.6	21	6.8	5.0	12.0	21.0
1980s	Year								
	1985	2	3	3.5	4	0.7	3.0	3.5	4.0
	1986	2	1	7.0	13	8.5	1.0	7.0	13.0
	1987	1	26	26.0	26		26.0	26.0	26.0
	1988	1	13	13.0	13		13.0	13.0	13.0
	Total	6	1	10.0	26	9.4	1.0	8.5	26.0
1990s	Year								
	1990	1	3	3.0	3		3.0	3.0	3.0
	1992	1	17	17.0	17		17.0	17.0	17.0
	1998	1	27	27.0	27		27.0	27.0	27.0
	Total	3	3	15.7	27	12.1	3.0	17.0	27.0
2000s	Year								
	2003	3	3	13.0	32	16.5	3.0	4.0	32.0
	2004	1	1	1.0	1		1.0	1.0	1.0
	2006	1	26	26.0	26		26.0	26.0	26.0
	2007	1	7	7.0	7		7.0	7.0	7.0
	2009	1	6	6.0	6		6.0	6.0	6.0
	2015	3	1	7.3	18	9.3	1.0	3.0	18.0
	Total	10	1	10.1	32	11.2	1.0	5.0	29.0
Total		26	1	11.6	32	9.4	1.0	8.5	26.0

Table 31. Min., mean and max. length (days) and total frequency of periods in which discharge in the lower HORSEFLY RIVER was continuously less than 8 cms (August-September), by year.

Monthly and Annual No. Dates > 375 cms

Decade	Year	Freq POT375 cms Dates		Total Days
		Aug	Sep	
1940s	1940	12		12
	1941			
	1942			
	1943	18		18
	1944	10		10
	1945			
	1946			
	1947	1		1
	1948	17	7	24
	1949	6		6
1950s	1950			
	1951			
	1952			
	1953			
	1954	19		19
	1955	24		24
	1956			
	1957			

(Continued)

Monthly and Annual No. Dates > 375 cms

Decade	Year	Freq POT375 cms Dates		Total Days
		Aug	Sep	
1950s	1958			
	1959		12	12
1960s	1960	15		15
	1961			
	1962	31	1	32
	1963	4		4
	1964	22	6	28
	1965	2		2
	1966	8		8
	1967	5		5
	1968	10		10
	1969	9		9
1970s	1970			
	1971	4		4
	1972	6		6
	1973			
	1974	13		13
	1975	8		8

(Continued)

Table 32. Annual total frequency of dates per month (August-September) in which observed or estimated discharge in the lower QUESNEL RIVER was greater than 375 cms (>85th percentile) August-September, by year (1940-2015).

Monthly and Annual No. Dates > 375 cms

Monthly and Annual No. Dates > 375 cms

Decade	Year	Freq POT375 cms Dates		Total Days
		Aug	Sep	
1970s	1976	31	18	49
	1977	8		8
	1978			
	1979			
1980s	1980			
	1981			
	1982	25	9	34
	1983	4		4
	1984	13		13
	1985			
	1986			
	1987			
	1988			
	1989			
1990s	1990			
	1991	5		5
	1992			
	1993			

Decade	Year	Freq POT375 cms Dates		Total Days
		Aug	Sep	
1990s	1994	2		2
	1995	23		23
	1996	19		19
	1997	12		12
	1998			
	1999	24		24
2000s	2000	14		14
	2001	26		26
	2002	3		3
	2003			
	2004		13	13
	2005			
	2006			
	2007			
	2008			
	2009			
	2010			
	2011	17		17
	2012	12		12
	2013			
	2014	5		5
	2015			

(Continued)

Table 32, cont'd. Annual total frequency of dates per month (August-September) in which observed or estimated discharge in the lower QUESNEL RIVER was greater than 375 cms (>85th percentile) August-September, by year (1940-2015).

		PDT Event Duration (days)							
		N	Min	Avg	Max	Std	P10	PED	P90
Decade	Year								
1940s	1940	1	12	12.0	12		12.0	12.0	12.0
	1943	1	18	18.0	18		18.0	18.0	18.0
	1944	1	10	10.0	10		10.0	10.0	10.0
	1947	1	1	1.0	1		1.0	1.0	1.0
	1948	2	10	12.0	14	2.8	10.0	12.0	14.0
	1949	1	8	8.0	8		8.0	8.0	8.0
	Total	7	1	10.1	18	5.5	1.0	10.0	18.0
1950s	Year								
	1954	2	5	9.0	13	5.7	5.0	9.0	13.0
	1955	1	24	24.0	24		24.0	24.0	24.0
	1959	3	2	4.0	6	2.0	2.0	4.0	6.0
	Total	6	2	9.0	24	8.2	2.0	5.5	24.0
1960s	Year								
	1960	3	2	4.7	10	4.6	2.0	2.0	10.0
	1962	1	32	32.0	32		32.0	32.0	32.0
	1963	2	2	2.0	2	0.0	2.0	2.0	2.0
	1964	3	2	9.3	20	9.5	2.0	6.0	20.0
	1965	1	2	2.0	2		2.0	2.0	2.0
	1966	1	8	8.0	8		8.0	8.0	8.0
	1967	1	5	5.0	5		5.0	5.0	5.0
	1968	1	10	10.0	10		10.0	10.0	10.0
	1969	2	1	4.0	7	4.2	1.0	4.0	7.0
	Total	15	1	7.4	32	8.5	2.0	5.0	20.0
1970s	Year								
	1971	1	4	4.0	4		4.0	4.0	4.0
	1972	1	6	6.0	6		6.0	6.0	6.0
	1974	1	13	13.0	13		13.0	13.0	13.0
	1975	1	8	8.0	8		8.0	8.0	8.0
	1976	1	49	49.0	49		49.0	49.0	49.0
	1977	1	8	8.0	8		8.0	8.0	8.0
	Total	6	4	14.7	49	17.1	4.0	8.0	49.0
		PDT Event Duration (days)							
		N	Min	Avg	Max	Std	P10	PED	P90
Decade	Year								
1980s	Year								
	1982	3	1	11.3	25	12.3	1.0	8.0	25.0
	1983	1	4	4.0	4		4.0	4.0	4.0
	1984	1	13	13.0	13		13.0	13.0	13.0
	Total	5	1	10.2	25	9.4	1.0	8.0	25.0
1990s	Year								
	1991	2	1	2.5	4	2.1	1.0	2.5	4.0
	1994	1	2	2.0	2		2.0	2.0	2.0
	1995	1	23	23.0	23		23.0	23.0	23.0
	1996	2	3	9.0	15	8.5	3.0	9.0	15.0
	1997	1	12	12.0	12		12.0	12.0	12.0
	1999	1	24	24.0	24		24.0	24.0	24.0
	Total	8	1	10.5	24	9.4	1.0	8.0	24.0
2000s	Year								
	2000	1	14	14.0	14		14.0	14.0	14.0
	2001	2	4	12.5	21	12.0	4.0	12.5	21.0
	2002	1	3	3.0	3		3.0	3.0	3.0
	2004	1	13	13.0	13		13.0	13.0	13.0
	2011	1	17	17.0	17		17.0	17.0	17.0
	2012	1	12	12.0	12		12.0	12.0	12.0
	2014	1	5	5.0	5		5.0	5.0	5.0
Total		8	3	11.1	21	6.5	3.0	12.5	21.0
Total		55	1	10.0	49	9.1	2.0	8.0	23.0

Table 33. Annual total frequency of dates per month (August-September) in which observed or estimated discharge in the lower Quesnel River was continuously greater than 375 cms (>85th percentile) August-September, by year (1940-2015).

FIGURES



Figure 1. Quesnel / Horsefly study area locator map (adapted from Cronkite et al. 2006).

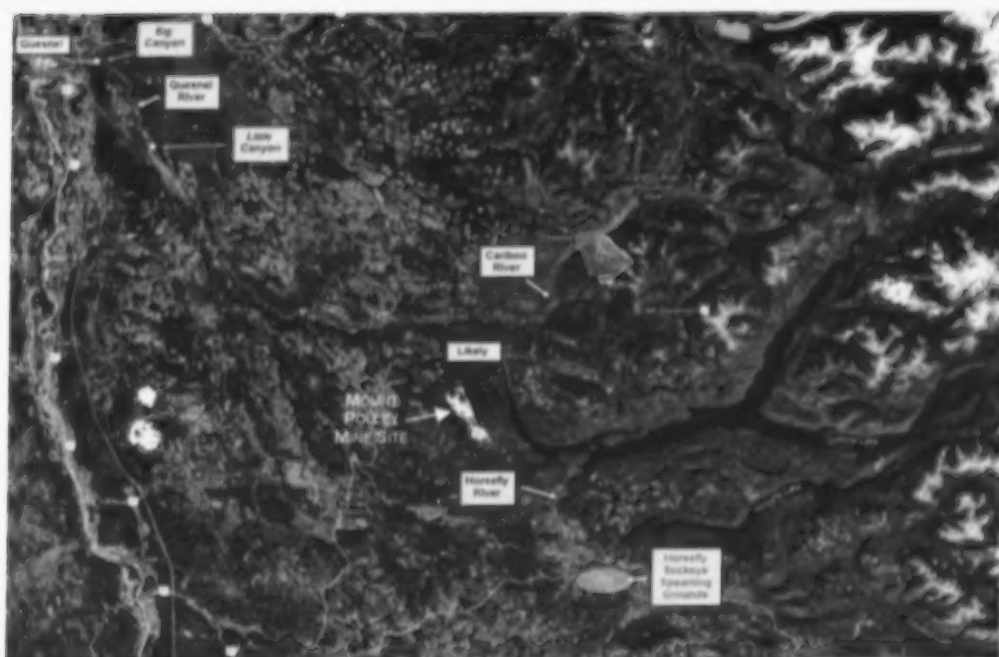


Figure 2. Quesnel / Horsefly study area (satellite map courtesy of Google Inc.).



Figure 3. The Quesnel Sockeye migration pathways (black lines), and Horsefly Sockeye spawning grounds and artificial spawning channel (DFO Mapster).

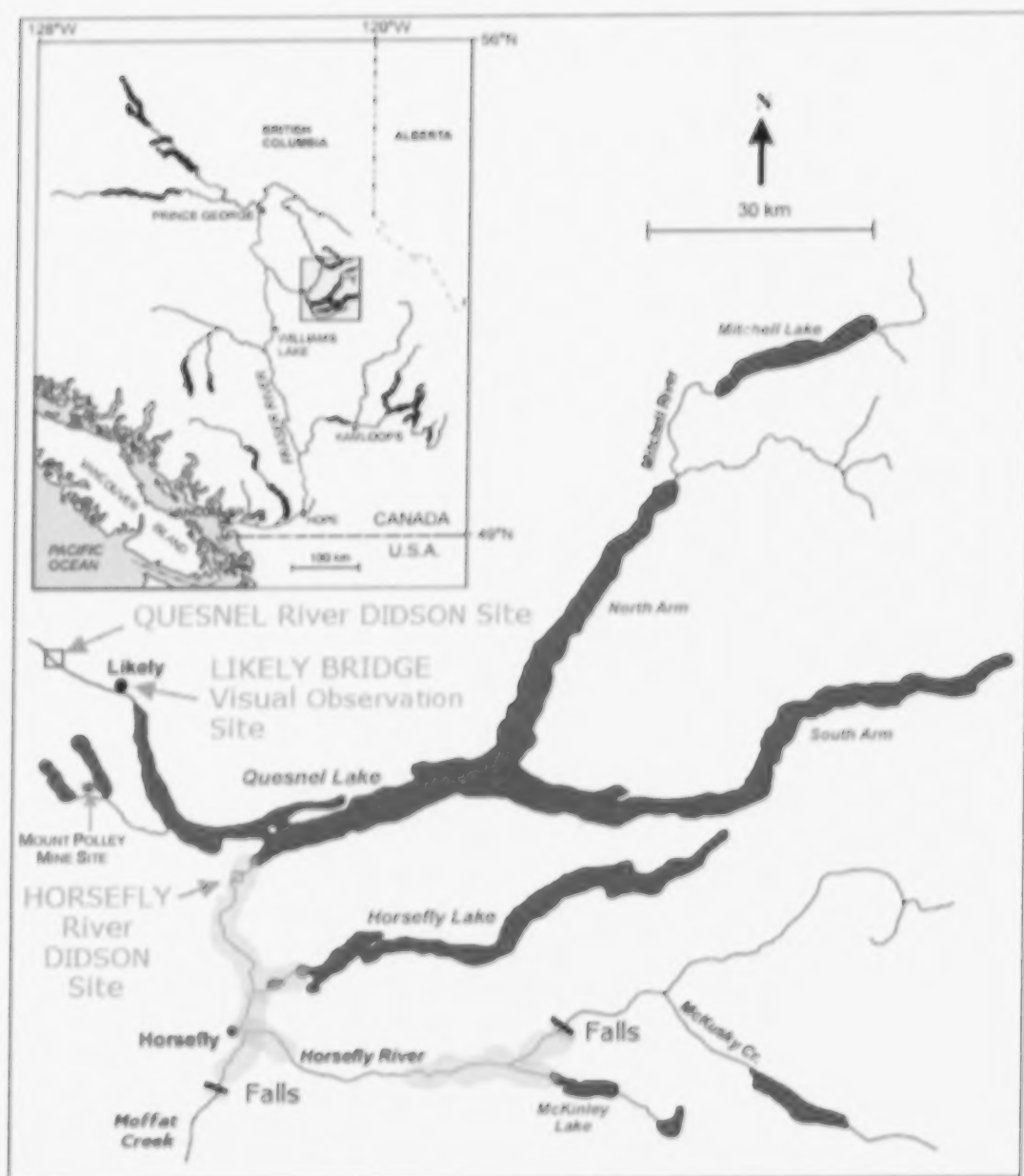


Figure 4. The Quesnel watershed Sockeye counter sites and potential spawning grounds for Horsefly Sockeye (adapted from Cronkite et al. 2006).

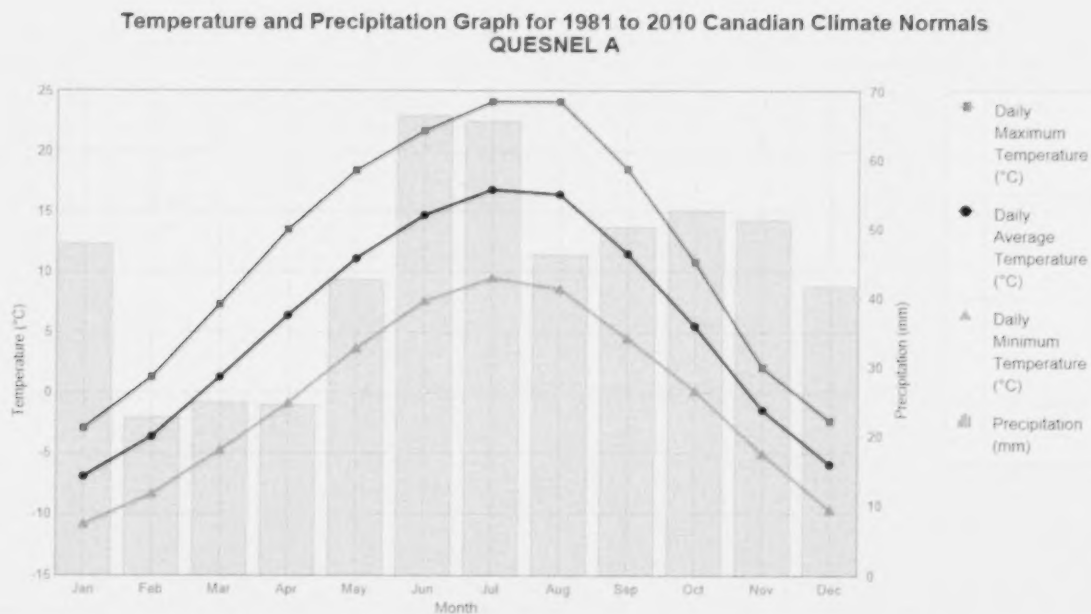


Figure 5. QUESNEL Climate Normals (1981-2010). Source: Environment Canada (http://climate.weather.gc.ca/climate_normals/index_e.html).



Figure 6. Site of rapids at Big Canyon, 14 km upstream of the Quesnel / Fraser confluence (source: DFO Mapster).

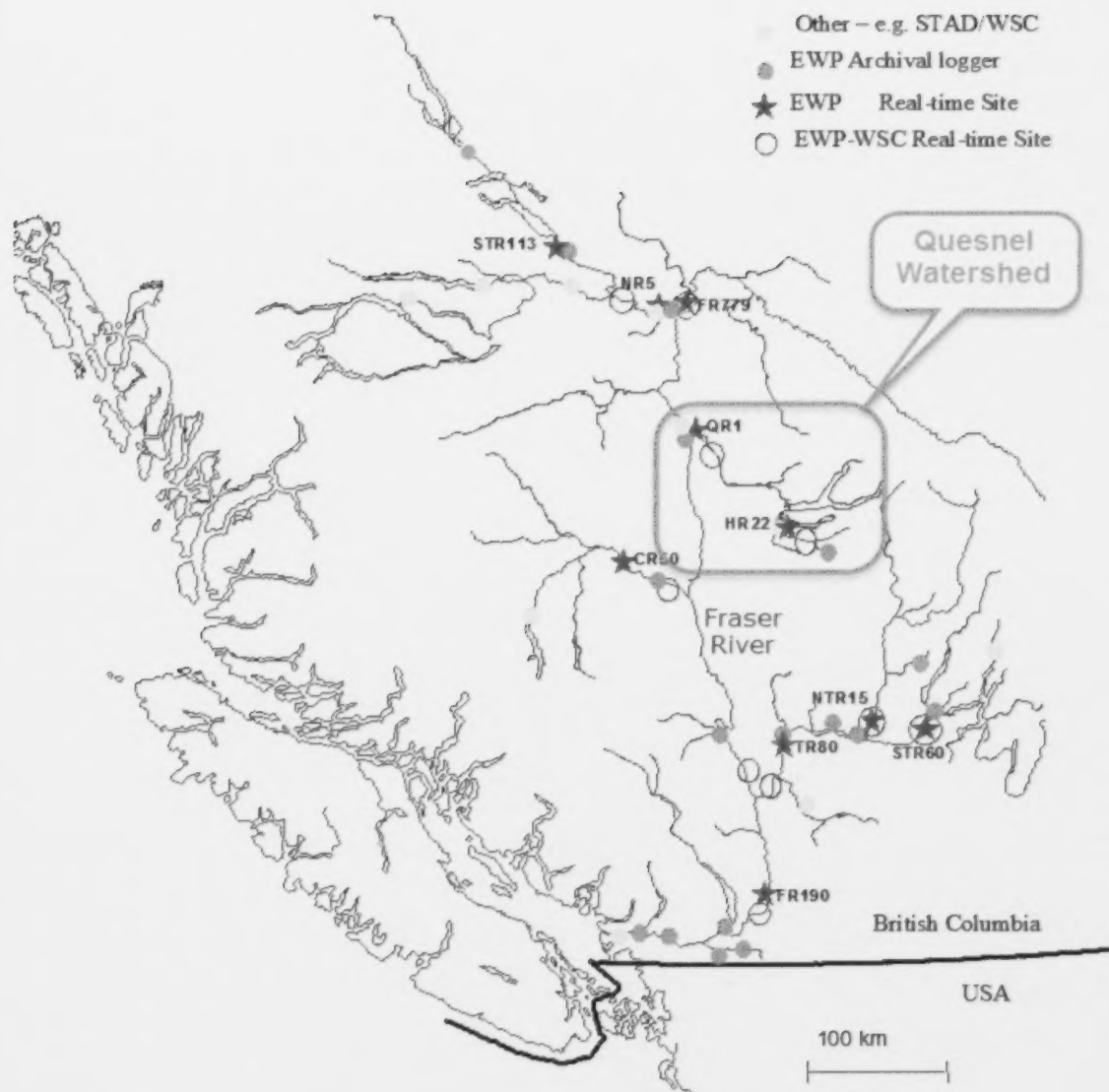
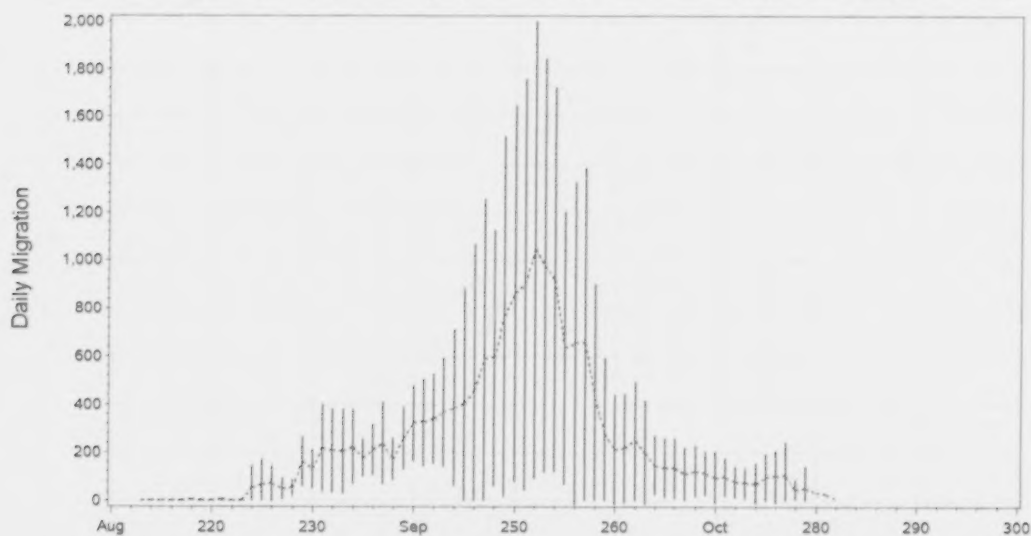


Figure 7. Quesnel / Horsefly study area with hydrometric and water temperature monitoring locations (map courtesy of DFO ENVIRONMENTAL WATCH PROGRAM). Blue stars represent real-time water temperature monitoring stations from EWP (e.g. QR1 - lower Quesnel River; HR22 - lower Horsefly River; FR190 - Fraser River at Qualark); green dots represent DFO Stock Assessment and/or WSC partner stations; red dots represent archival temperature monitoring locations; clear circles represent matching EWP/WSC real-time hydrometric locations.

LikelyBridge Average Daily Counts (1993-1995, 1997-1998, 2001)



LikelyBridge Daily Migration Rate (1993-1995, 1997-1998, 2001)

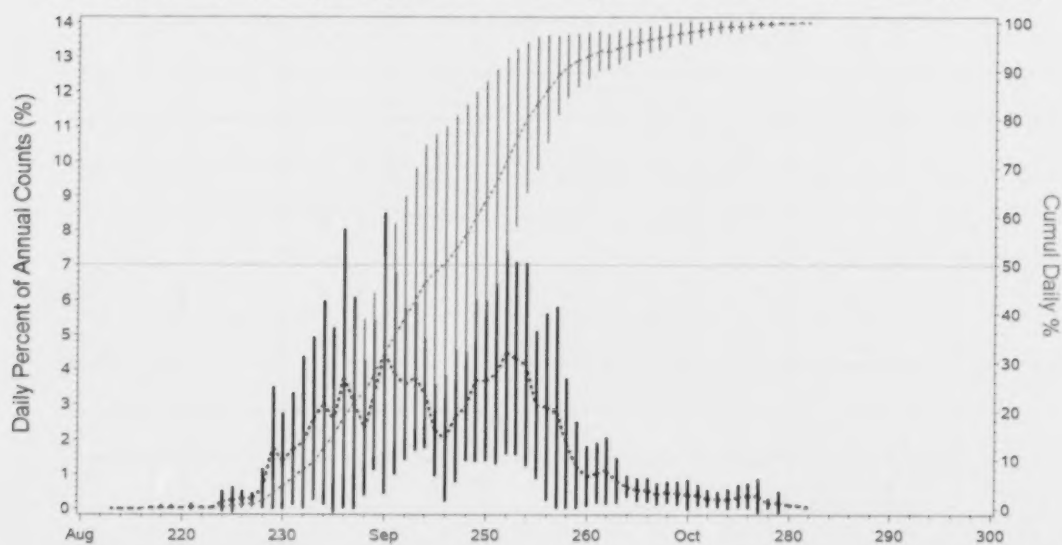
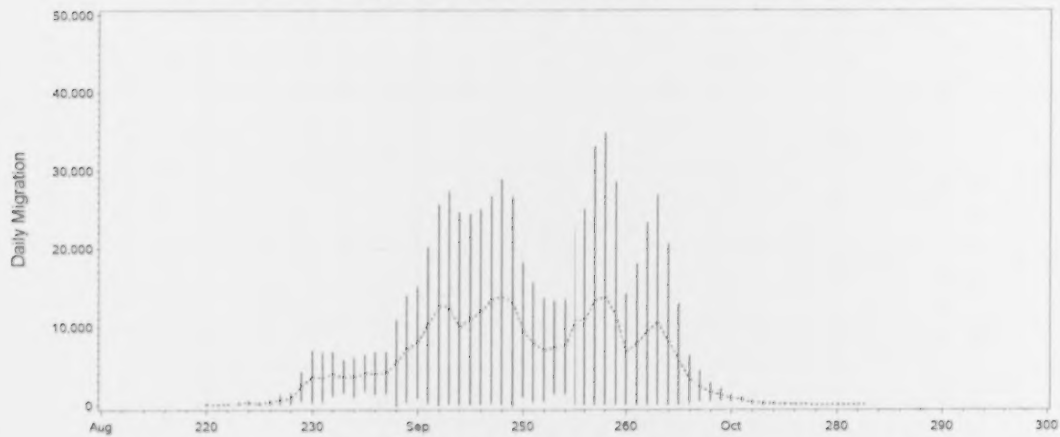


Figure 8. Historical Sockeye migration timing based on mean daily visual counts in Quesnel River from Likely Bridge (1993, 1994, 1995, 1997, 1998, 2001). Mean and variance (95% CI) of average daily migrant counts (top) and mean daily % and cumulative % of total annual escapement (bottom). Time-to-50% ~ day 245 ~ September 2nd (Source: DFO Stock Assessment, Fraser Division).

Quesnel Average Daily Counts (2009, 2010 2014, 2015)



Quesnel Daily Migration Rate (2009, 2010 2014, 2015)

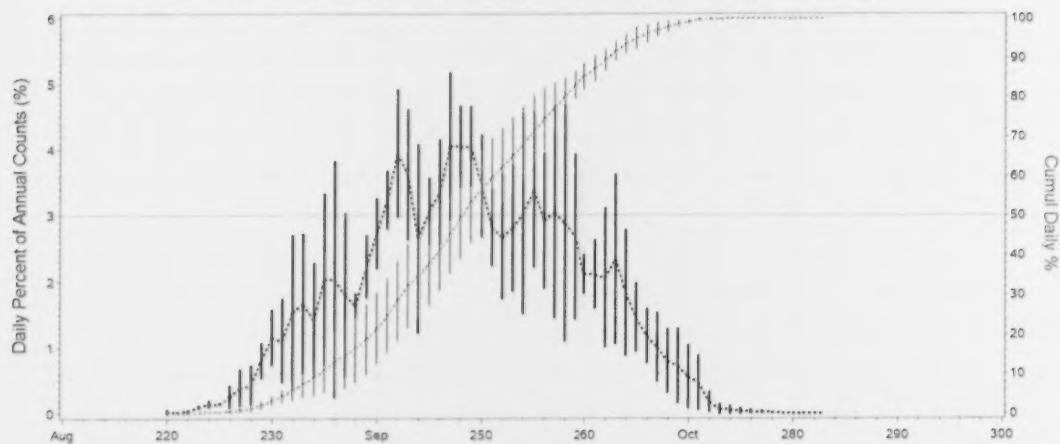
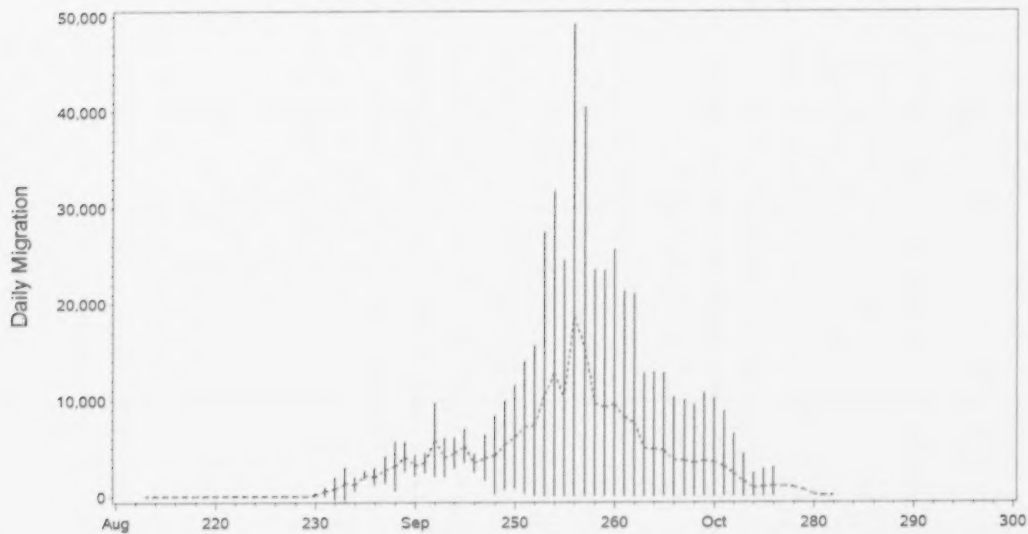


Figure 9. Sockeye multi-year migration timing based on DIDSON acoustic counts in Quesnel River (2009-2010, 2014-2015). Mean and variance (95% CI) of average daily migrant counts (top) and mean daily % and cumulative % of total annual escapement (bottom). Time-to-50% ~ day 248 ~ September 5th (Source: DFO Stock Assessment, Fraser Division).

Horsefly Average Daily Counts (2005, 2006, 2007, 2010)



Horsefly Daily Migration Rate (2005, 2006, 2007, 2010)

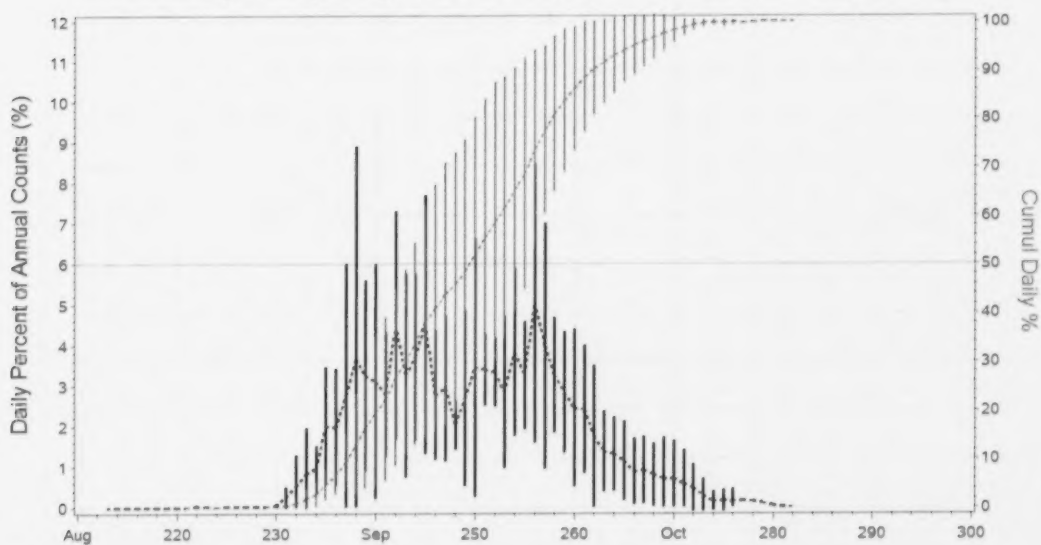


Figure 10. Sockeye multi-year migration timing based on DIDSON acoustic counts in Horsefly River (2005-2007, 2010). Mean and variance (95% CI) of average daily migrant counts (top) and mean daily % and cumulative % of total annual escapement (bottom). Time-to-50% ~ day 250 ~ September 7th (Source: DFO Stock Assessment, Fraser Division).

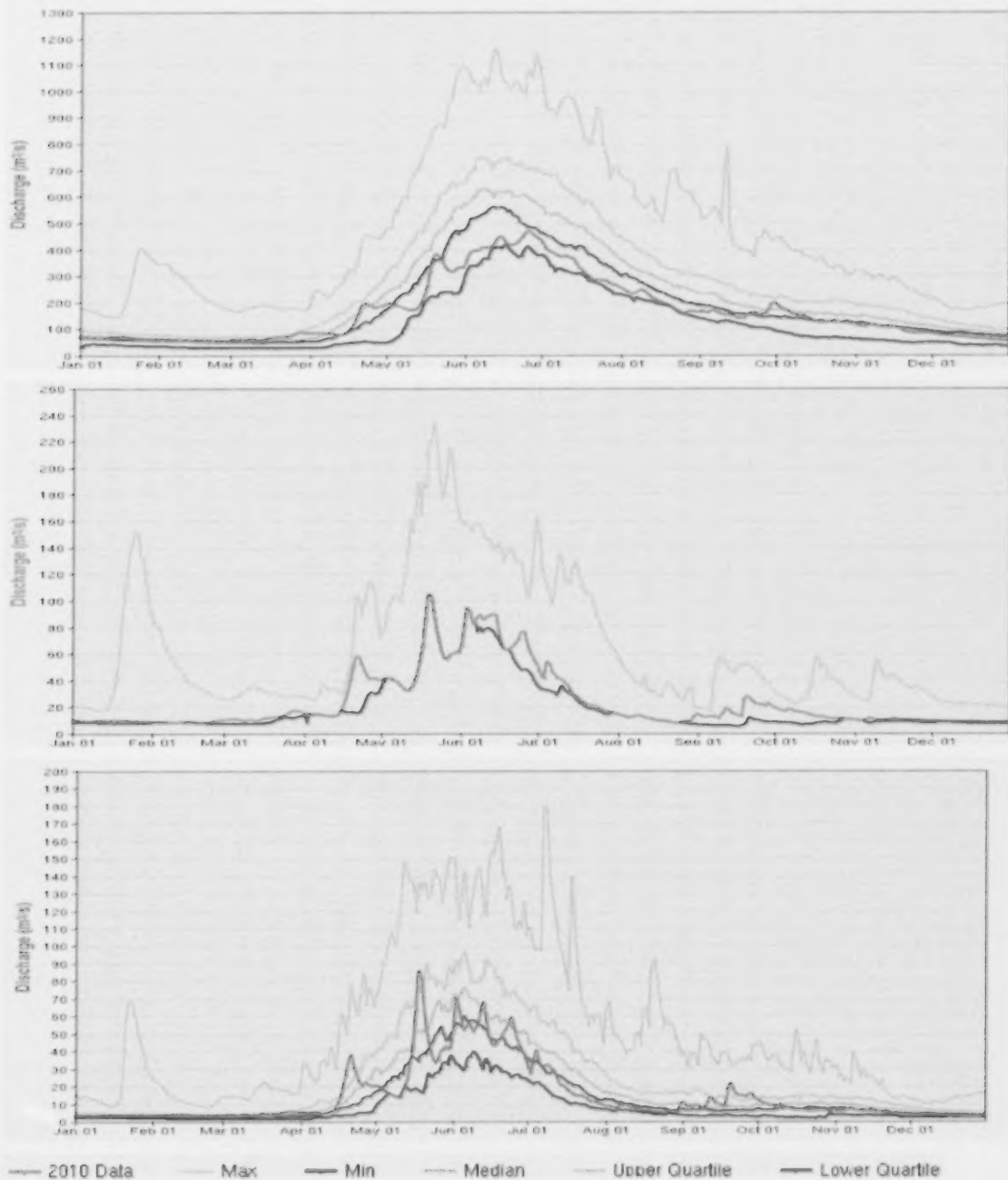


Figure 11. Watershed hydrology (source: Environment Canada)

- Quesnel River near Quesnel (WSC 08KH006) 1939-2013 (top);
- Horsefly River above Quesnel Lake (08MA001) 2004-2011 (middle);
- Horsefly River above McKinley Creek (08KH010 1955-2013 (bottom).

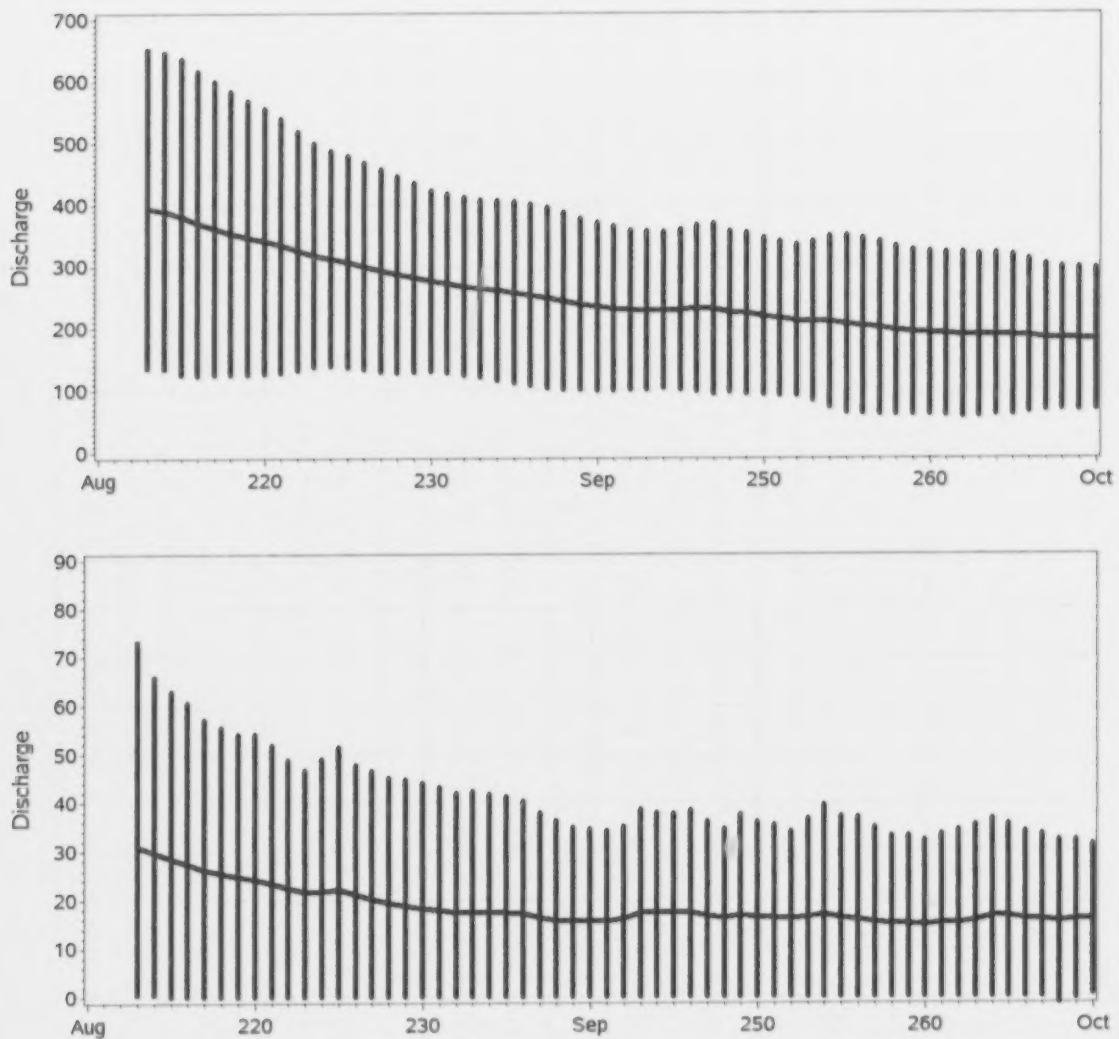


Figure 12. Daily mean discharge (cms) $\pm$ standard deviation during the Sockeye migration period (Aug-Sep, 1990-2015) for observed data from lower Quesnel River at Quesnel (08KH003, top), and lower Horsefly River above Quesnel Lake (08KH031, bottom; observed data 2004-2006, 2008-2015, estimated data otherwise (1990-2003, 2007)).

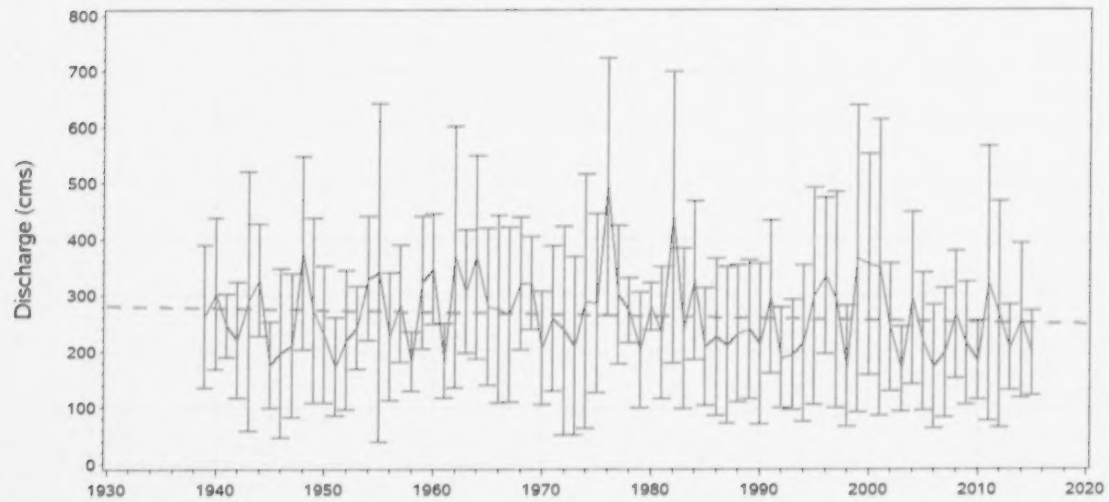


Figure 13. Observed lower QUESNEL RIVER (NEAR QUESNEL) mean discharge $\pm$ 2 std deviations, August-September, 1939-2015. Long-term trend of -3.6 cms per decade was not statistically significant ($P > 0.10$).

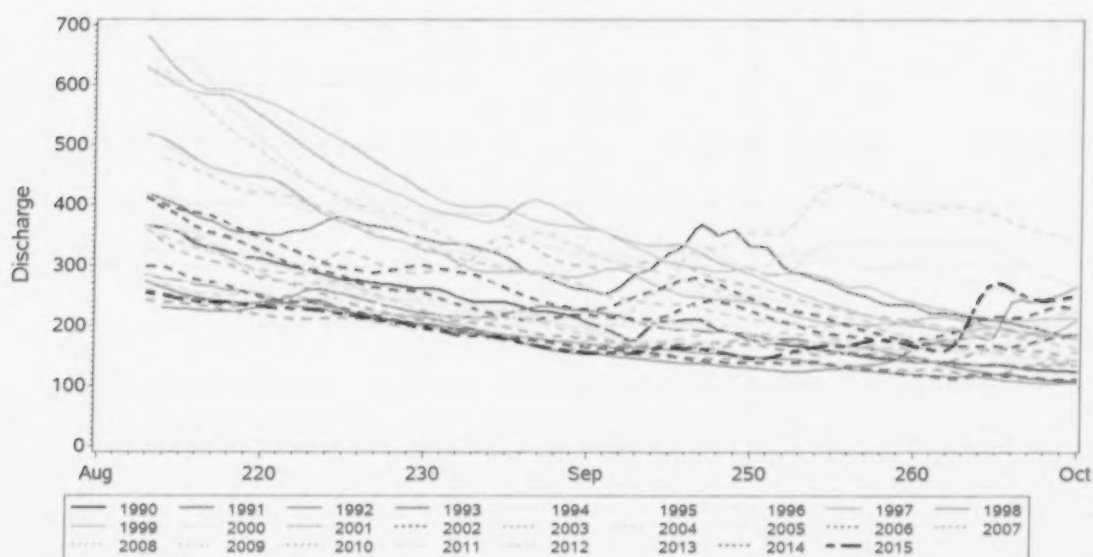


Figure 14. Lower QUESNEL RIVER NEAR QUESNEL mean daily discharge (cms) by year, August-September, 1990-2015.

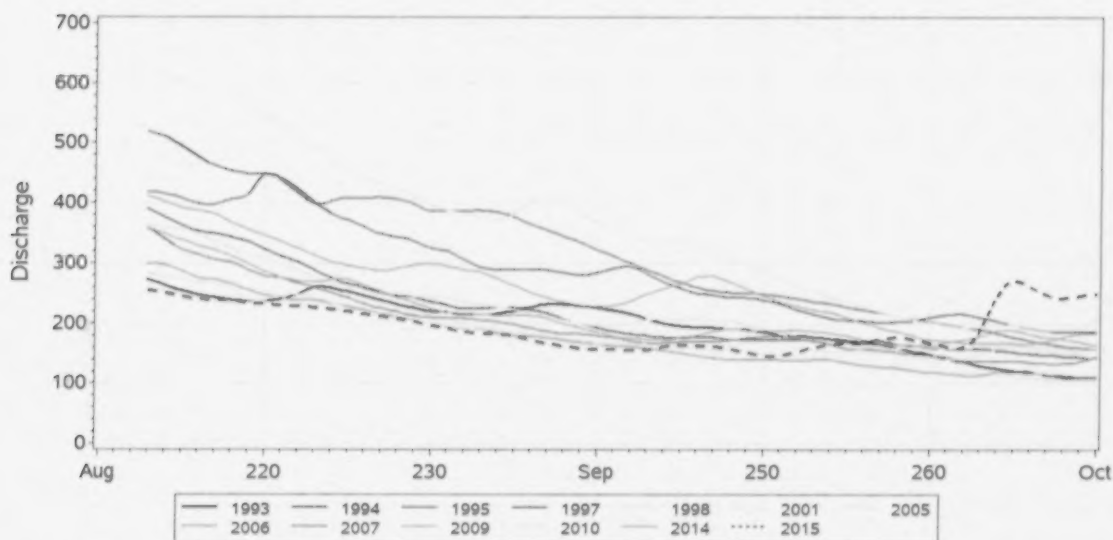


Figure 15. Lower QUESNEL RIVER NEAR QUESNEL mean daily discharge (cms) by year, August-September. Includes years of available Sockeye counts only.

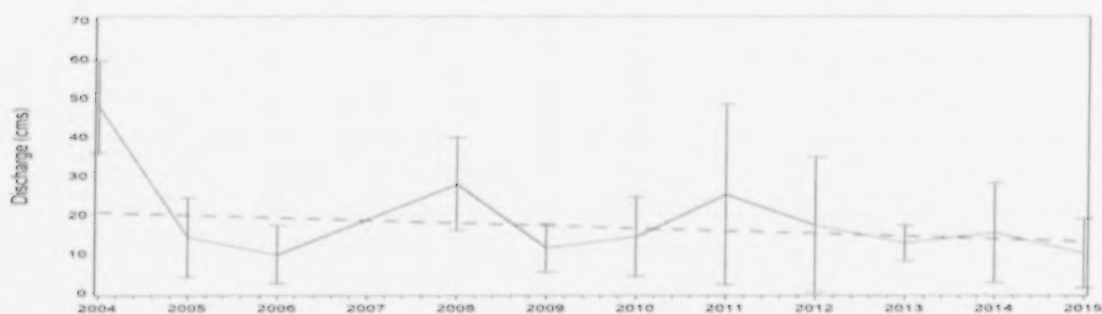


Figure 16. Lower HORSEFLY RIVER ABOVE QUESNEL LAKE - mean discharge ± 2 std deviations, August-September 2004-2015. Negative trend in time-series of -6.7 cms per decade ($P < 0.001$).

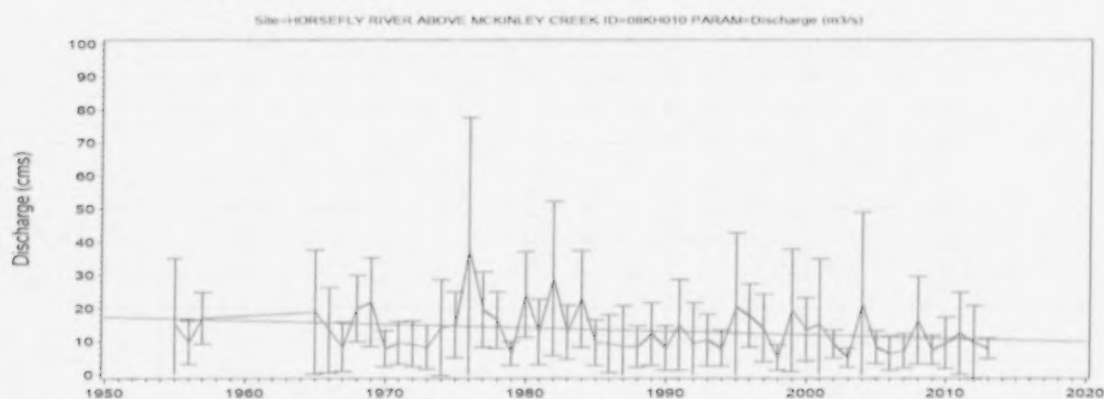


Figure 17. Upper HORSEFLY RIVER ABOVE MCKINLEY CREEK - mean discharge ± 2 std deviations, August-September 1955-2013. Negative trend in time-series of -1 cms per decade ($P < 0.001$).

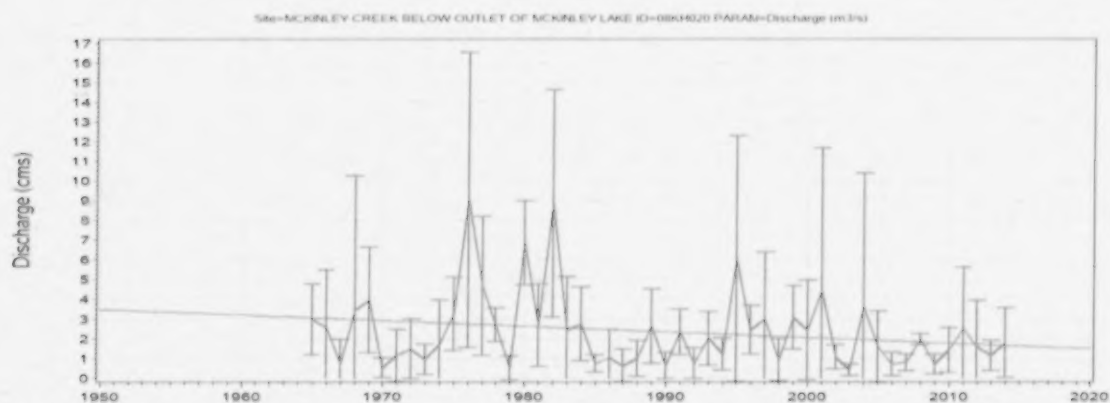


Figure 18. MCKINLEY CREEK - mean discharge ± 2 std deviations, August-September 1965-2014. Negative trend in time-series of -3 cms per decade ($P < 0.001$).

Site=HORSEFLY RIVER ABOVE MCKINLEY CREEK ID=08KH010 PARAM=Discharge (m³/s)

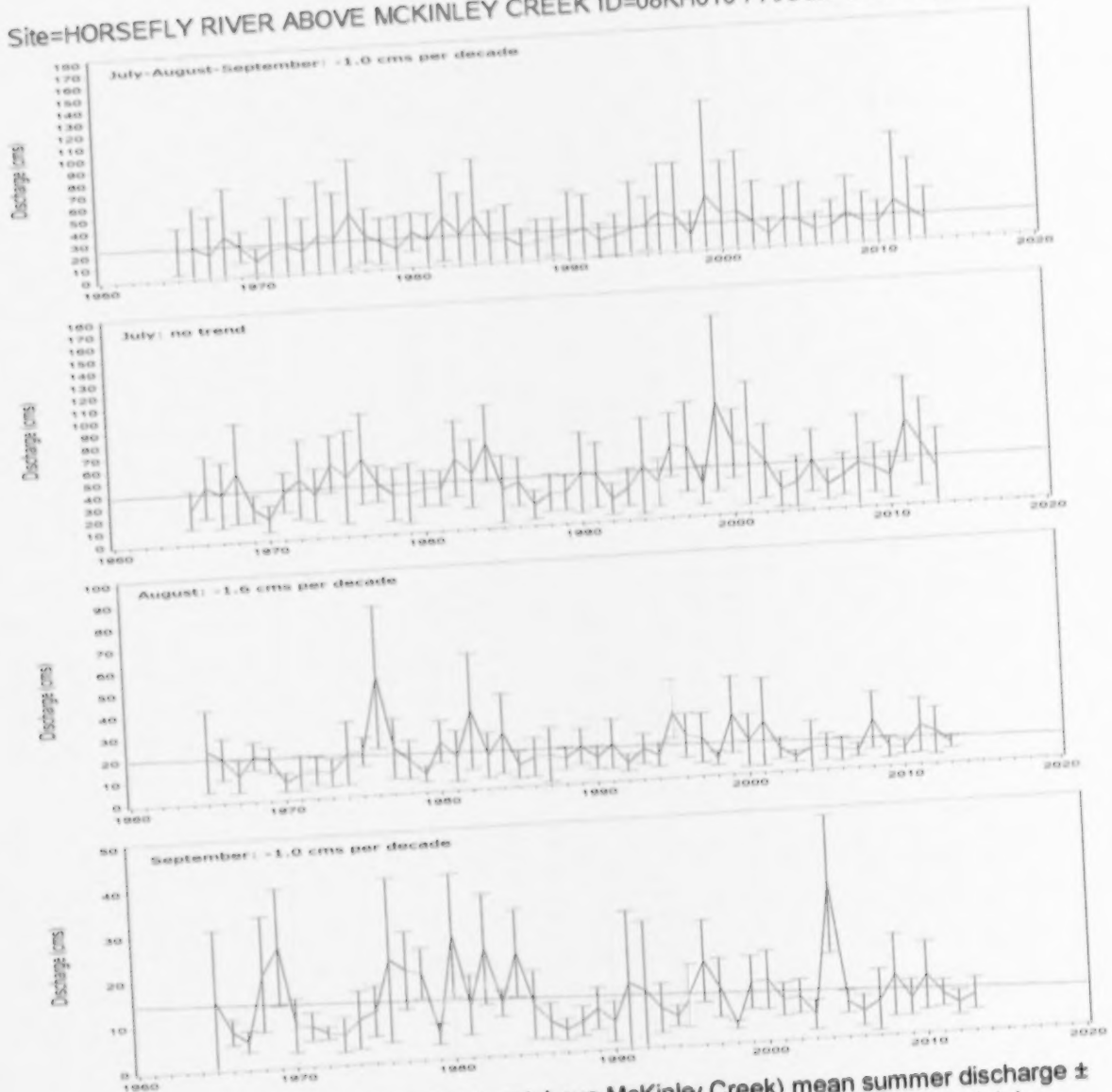


Figure 19. Observed upper Horsefly River (above McKinley Creek) mean summer discharge $\pm$ 2 standard deviations, 1965-2013. Summer seasonal discharge (combined July-August-September; top) shows minor significant trend due principally to diminishing flows in August and September, while July shows no significant trend.

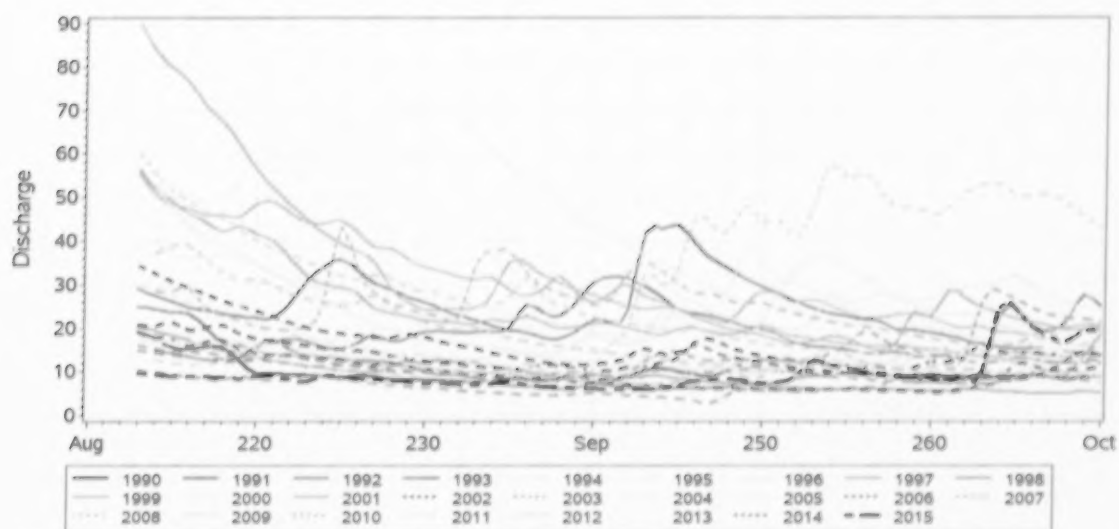


Figure 20. HORSEFLY RIVER ABOVE QUESNEL LAKE mean daily discharge (cms) by year, August-September, 1990-2015.

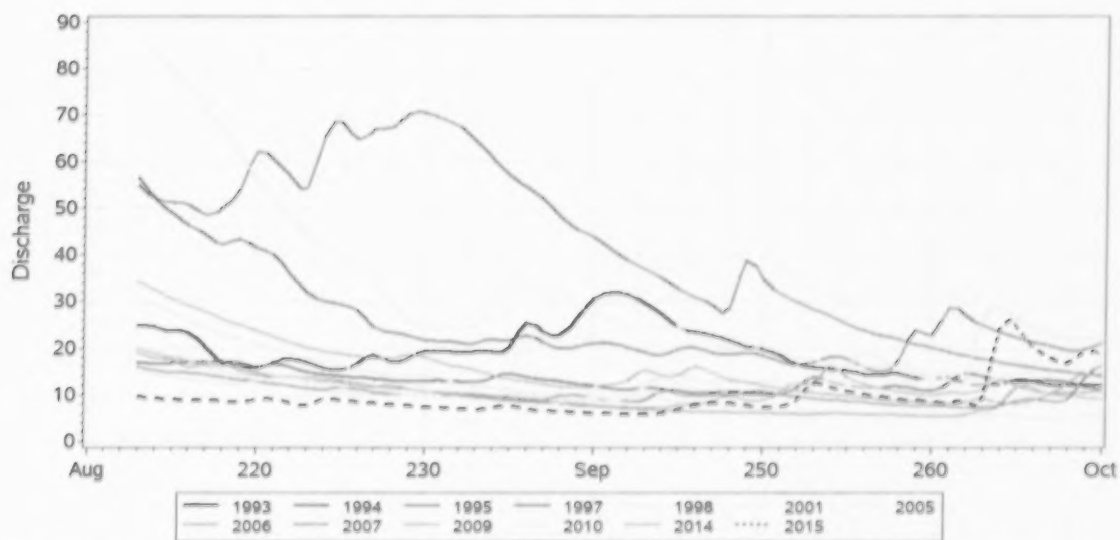
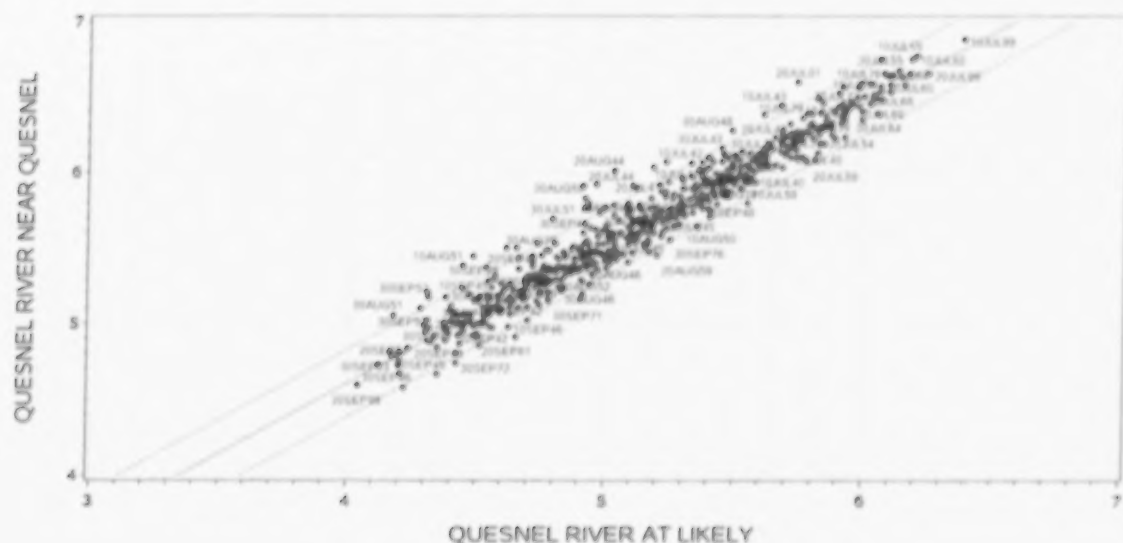
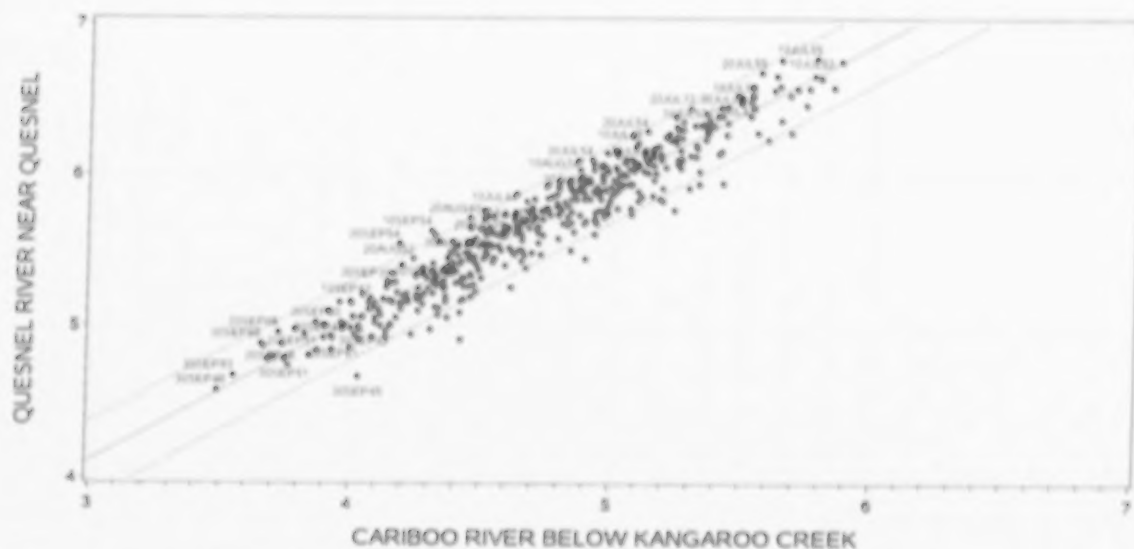


Figure 21. HORSEFLY RIVER ABOVE QUESNEL LAKE mean daily discharge (cms) by year, August-September. Includes years of available daily Sockeye counts only.



The REG Procedure						
Model: MODEL1						
Dependent Variable: _O0KH006 QUESNEL RIVER NEAR QUESNEL						
Number of Observations Read			792			
Number of Observations Used			692			
Number of Observations with Missing Values			100			
Analysis of Variance						
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model	1	136.00441	136.00441	10776.6	<.0001	
Error	690	8.70806	0.01262			
Lack of Fit	318	3.82779	0.01204	0.92	0.7860	
Pure Error	372	4.88028	0.01312			
Corrected Total	691	144.71248				
Root MSE		0.11234	R-Square	0.9398		
Dependent Mean		5.67751	Adj R-Sq	0.9397		
Coeff Var		1.97869				
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t
Intercept	Intercept	1	0.07761	0.04643	10.90	<.0001
_O0KH001	QUESNEL RIVER AT LIKELY	1	0.93152	0.00897	103.91	<.0001

Figure 22. Log-log plot and regression analysis of mean daily discharge (cms) in the lower QUESNEL RIVER NEAR QUESNEL as a function of mean daily discharge in the upper QUESNEL RIVER NEAR LIKELY during the adult Sockeye migration period (July-September, 1938-2015). Regression parameter estimates for the final $Y = aX^b$ model were $a = 1.137$ and $b = 0.99$ (based on ANOVA results, bottom).



The REG Procedure						
Model: MODEL 1						
Dependent Variable: _00KH006 QUESNEL RIVER NEAR QUESNEL						
Number of Observations Read			792			
Number of Observations Used			492			
Number of Observations with Missing Values			300			
Analysis of Variance						
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model	1	89.58177	89.58177	5203.39	<.0001	
Error	490	8.43585	0.01722			
Lack of Fit	282	4.96980	0.01762	1.06	0.3352	
Pure Error	208	3.46605	0.01666			
Corrected Total	491	98.01763				
Root MSE		0.13121	R-Square	0.9139		
Dependent Mean		5.68730	Adj R-Sq	0.9130		
Coeff Var		2.30707				
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t
Intercept	Intercept	1	1.35073	0.06041	22.36	<.0001
_00KH006	CARIBOO RIVER BELOW KANGAROO CREEK	1	0.91882	0.01274	72.13	<.0001

Figure 23. Log-log plot and regression analysis of mean daily discharge (cms) in the lower QUESNEL RIVER NEAR QUESNEL as a function of mean daily discharge in the tributary CARIBOO RIVER during the adult Sockeye migration period (July-September, 1928-1994).

The REG Procedure					
Model: MODEL 1					
Dependent Variable: _08KH006 QUESNEL RIVER NEAR QUESNEL					
Number of Observations Read				792	
Number of Observations Used				492	
Number of Observations with Missing Values				300	
Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	95.11514	47.55757	8012.32	<.0001
Error	489	2.90249	0.00594		
Lack of Fit	485	2.89578	0.00597	3.56	0.1097
Pure Error	4	0.00671	0.00168		
Corrected Total	491	98.01763			
Root MSE		0.07704	R-Square	0.9704	
Dependent Mean		5.68730	Adj R-Sq	0.9703	
Coeff Var		1.35464			
Parameter Estimates					
Variable	Label	DF	Parameter Estimate	Standard Error	t Value Pr > t
Intercept	Intercept	1	0.85036	0.03907	21.76 <.0001
_08KH001	QUESNEL RIVER AT LIKELY	1	0.52934	0.01734	30.53 <.0001
_08KH003	CARIBOD RIVER BELOW KANGAROD CREEK	1	0.44474	0.01723	25.81 <.0001

Figure 24. Multi-variate log-log plot and regression analysis of mean daily discharge (cms) in the lower QUESNEL RIVER NEAR QUESNEL as a function of mean daily discharge in the upper QUESNEL RIVER NEAR LIKELY and the tributary CARIBOO RIVER during the adult Sockeye migration period (July-September, 1938-1994).

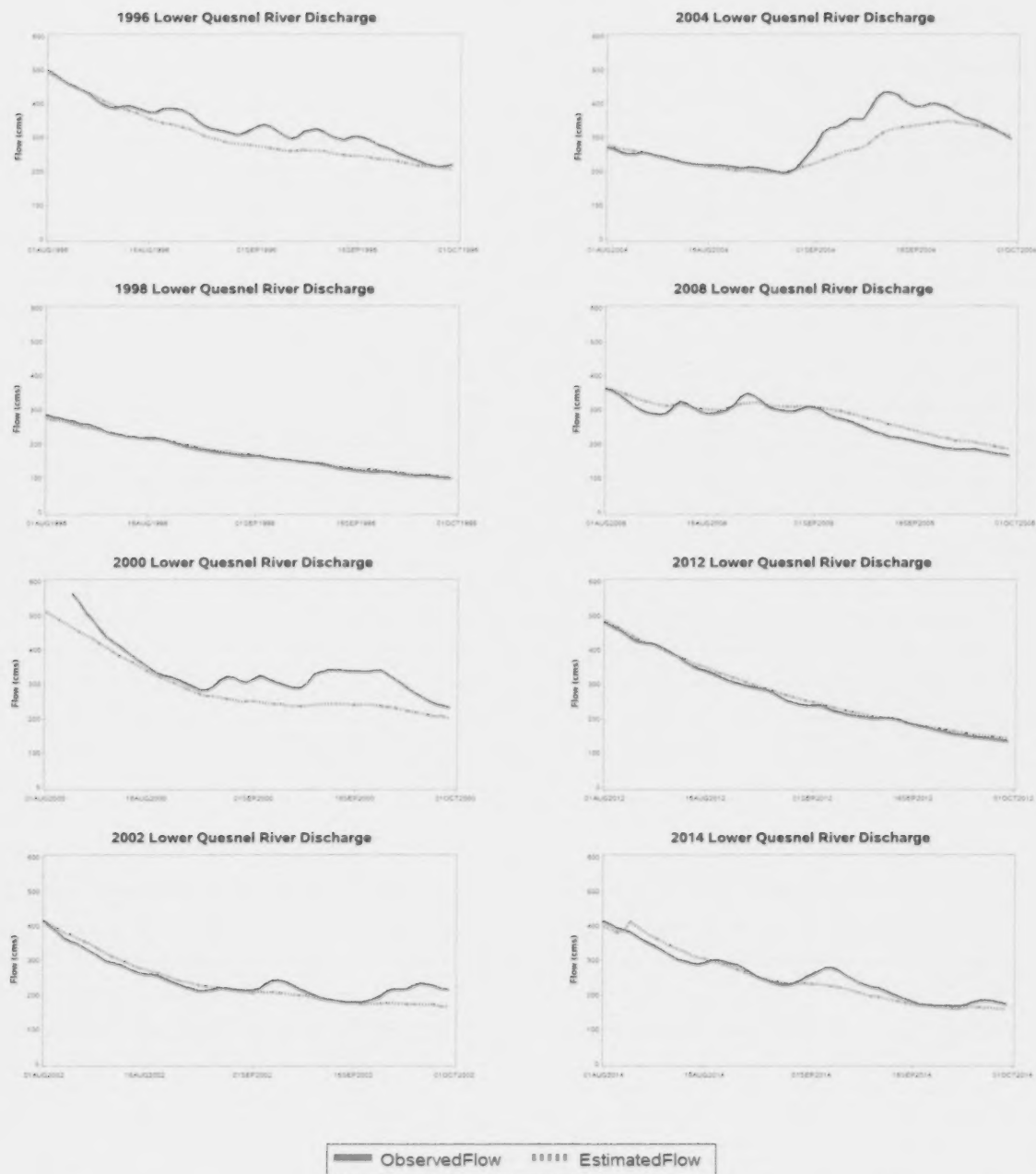
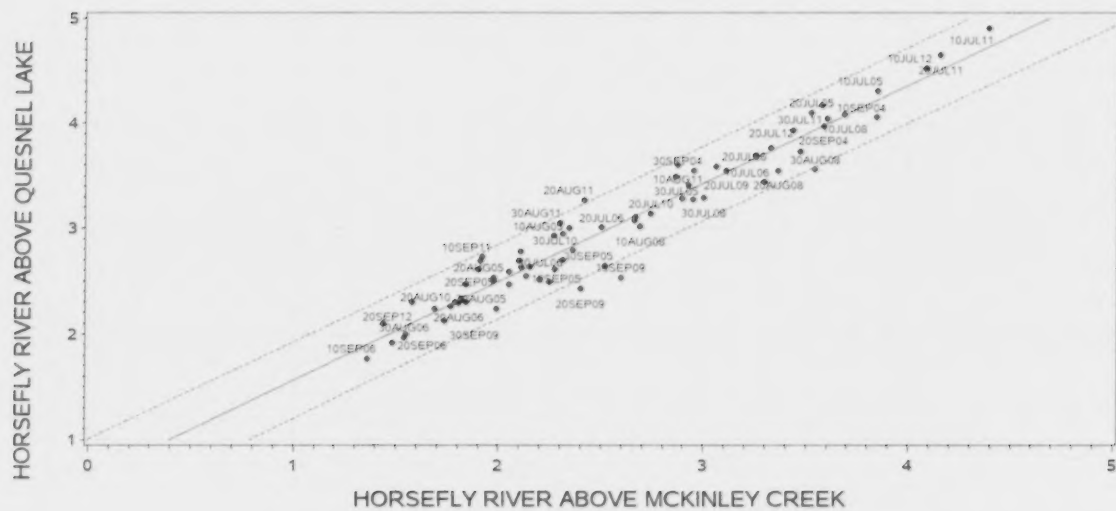
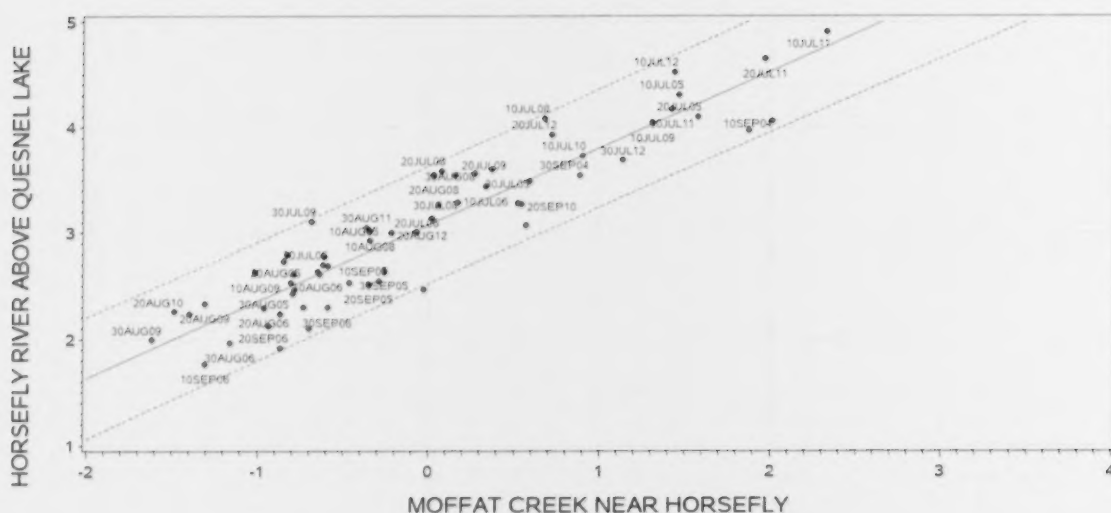


Figure 25. Observed (green line) and estimated (green dashed line) daily discharge (cms) in the lower QUESNEL RIVER NEAR QUESNEL (station 08KH006) based on log-log multiple regression with upper QUESNEL RIVER NEAR LIKELY (station 08KH001) and/or CARIBOO CREEK (station 08KH003) daily discharge.



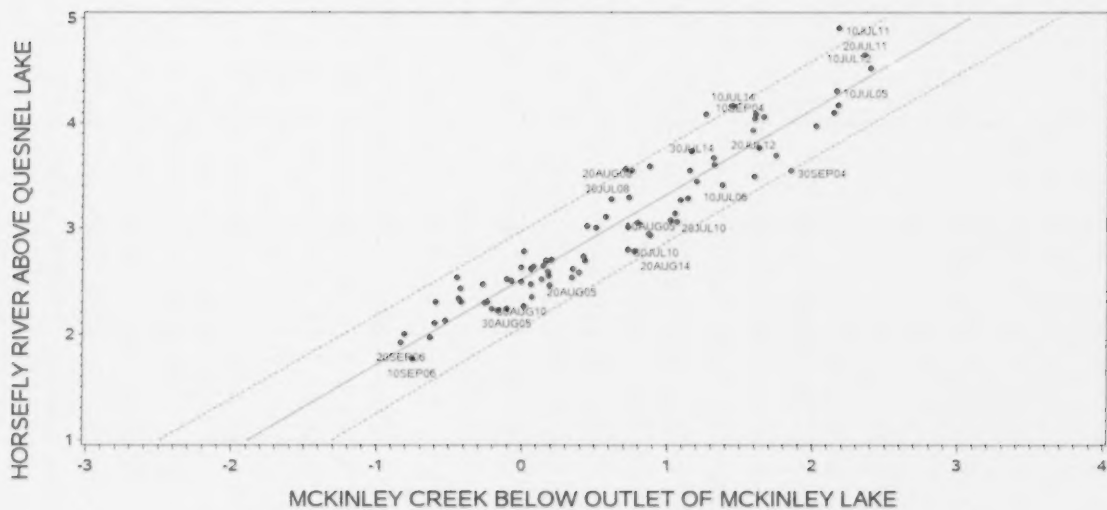
Lower Horsefly River Relations						
The REG Procedure						
Model: MODEL1						
Dependent Variable: _08KH031 HORSEFLY RIVER ABOVE QUESNEL LAKE						
Number of Observations Read		792				
Number of Observations Used		72				
Number of Observations with Missing Values		720				
Analysis of Variance						
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model	1	34.72327	34.72327	1133.82	<.0001	
Error	70	2.14375	0.03062			
Lack of Fit	69	2.11420	0.03064	1.04	0.6704	
Pure Error	1	0.02954	0.02954			
Corrected Total	71	36.86701				
Root MSE		0.17500	R-Square	0.9419		
Dependent Mean		3.01761	Adj R-Sq	0.9410		
Coeff Var		5.79928				
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t
Intercept	Intercept	1	0.62995	0.07385	8.53	<.0001
_08KH010	HORSEFLY RIVER ABOVE MCKINLEY	1	0.93435	0.02775	33.67	<.0001

Figure 26. Log-log plot and regression analysis of mean daily discharge (cms) in the lower HORSEFLY RIVER ABOVE QUESNEL LAKE as a function of mean daily discharge in the upper HORSEFLY RIVER ABOVE MCKINLEY CREEK during the adult Sockeye migration period (July-September, 2004-2013).



The REG Procedure						
Model: MODEL1						
Dependent Variable: _08KH031 HORSEFLY RIVER ABOVE QUESNEL LAKE						
Number of Observations Read			792			
Number of Observations Used			63			
Number of Observations with Missing Values			729			
Analysis of Variance						
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model	1	29.89515	29.89515	396.61	<.0001	
Error	61	4.59795	0.07538			
Lack of Fit	57	4.30762	0.07557	1.04	0.5637	
Pure Error	4	0.29033	0.07258			
Corrected Total	62	34.49310				
Root MSE		0.27455	R-Square	0.8667		
Dependent Mean		3.04870	Adj R-Sq	0.8645		
Coeff Var		9.00539				
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t
Intercept	Intercept	1	3.08092	0.03463	88.97	<.0001
_08KH019	MOFFAT CREEK NEAR HORSEFLY	1	0.72332	0.03632	19.92	<.0001

Figure 27. Log-log plot and regression analysis of mean daily discharge (cms) in the lower HORSEFLY RIVER ABOVE QUESNEL LAKE as a function of mean daily discharge in the tributary MOFFAT CREEK during the adult Sockeye migration period (July-September, 2004-2012).



The REG Procedure						
Model: MODEL1						
Dependent Variable: _08KH031 HORSEFLY RIVER ABOVE QUESNEL LAKE						
Number of Observations Read		792				
Number of Observations Used		81				
Number of Observations with Missing Values		711				
Analysis of Variance						
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model	1	37.29664	37.29664	722.10	<.0001	
Error	79	4.08037	0.05165			
Lack of Fit	75	3.76236	0.05016	0.63	0.8129	
Pure Error	4	0.31801	0.07950			
Corrected Total	80	41.37701				
Root MSE		0.22727	R-Square	0.9014		
Dependent Mean		3.02012	Adj R-Sq	0.9001		
Coeff Var		7.52510				
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t
Intercept	Intercept	1	2.52392	0.03128	80.68	<.0001
_08KH020	MCKINLEY CREEK BELOW OUTLET OF MCKINLEY LAKE	1	0.80851	0.03009	26.87	<.0001

Figure 28. Log-log plot and regression analysis of mean daily discharge (cms) in the lower HORSEFLY RIVER ABOVE QUESNEL LAKE as a function of mean daily discharge in the tributary MCKINLEY CREEK during the adult Sockeye migration period (July-September, 2004-2014).

Lower Horsefly River Relations					
The REG Procedure					
Model: MODEL1					
Dependent Variable: _08KH031 HORSEFLY RIVER ABOVE QUESNEL LAKE					
Number of Observations Read				792	
Number of Observations Used				63	
Number of Observations with Missing Values				729	
Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	33.66301	11.22127	798.34	<.0001
Error	59	0.82929	0.01406		
Lack of Fit	59	0.82929	0.01406		
Pure Error	0	0			
Corrected Total	62	34.49310			
Root MSE		0.11856	R-Square	0.9760	
Dependent Mean		3.04870	Adj R-Sq	0.9747	
Coeff Var		3.88878			
Parameter Estimates					
Parameter	DF	Estimate	Standard Error	t Value	Pr > t
Intercept	1	1.390357	0.097675	14.23	<.0001
_08KH010	1	0.553451	0.045686	12.11	<.0001
_08KH020	1	0.361722	0.039431	9.17	<.0001

Figure 29. Multi-variate log-log plot and regression analysis of mean daily discharge (cms) in the lower HORSEFLY RIVER ABOVE QUESNEL LAKE as a function of mean daily discharge in the upper HORSEFLY RIVER ABOVE MCKINLEY CREEK (station 08KH010) and the tributary MCKINLEY CREEK (station 08KH020) during the adult Sockeye migration period (July-September, 2004-2012).

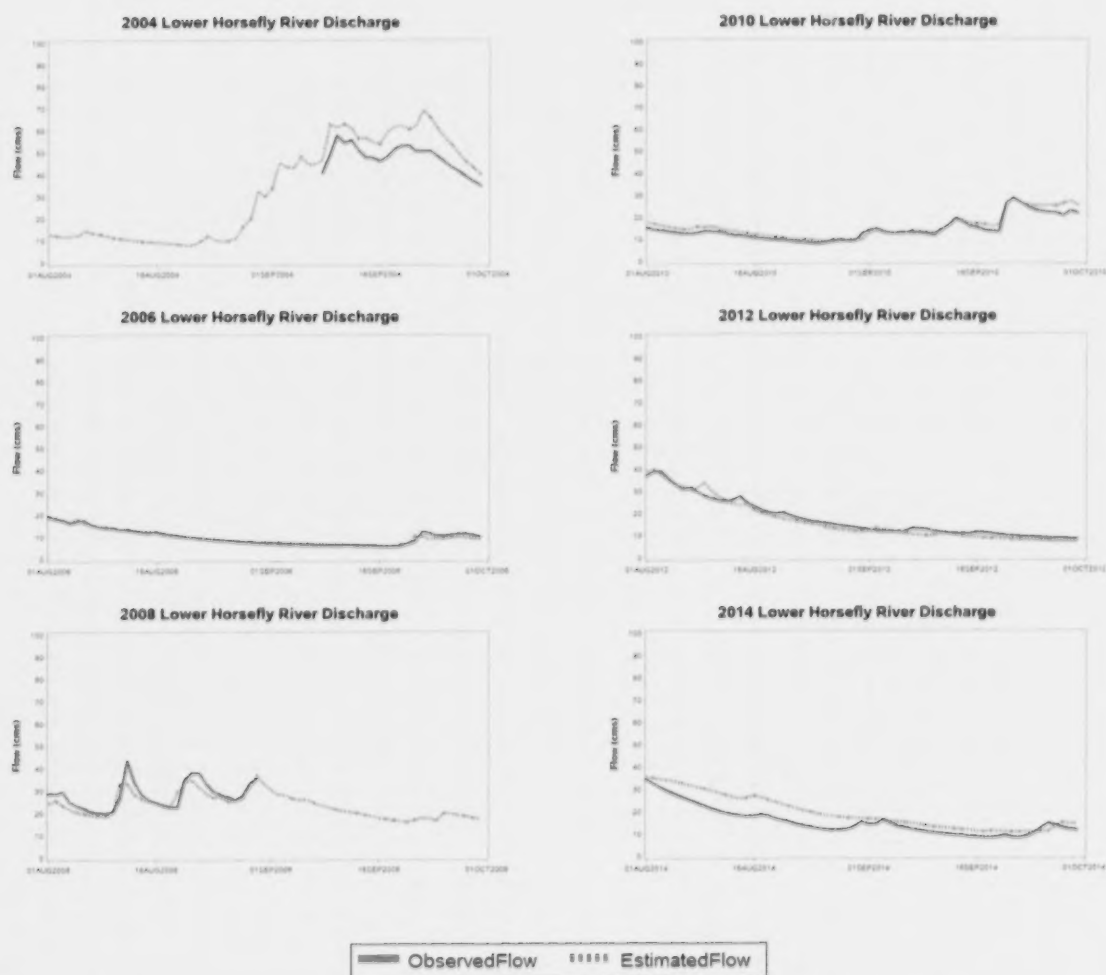


Figure 30. Observed (green line) and estimated (green dashed line) daily discharge (cms) in the lower HORSEFLY RIVER ABOVE QUESNEL LAKE based on log-log multiple regression with upper HORSEFLY RIVER ABOVE MCKINLEY (station 08KH010) and/or MCKINLEY CREEK (station 08KH020) daily discharge.

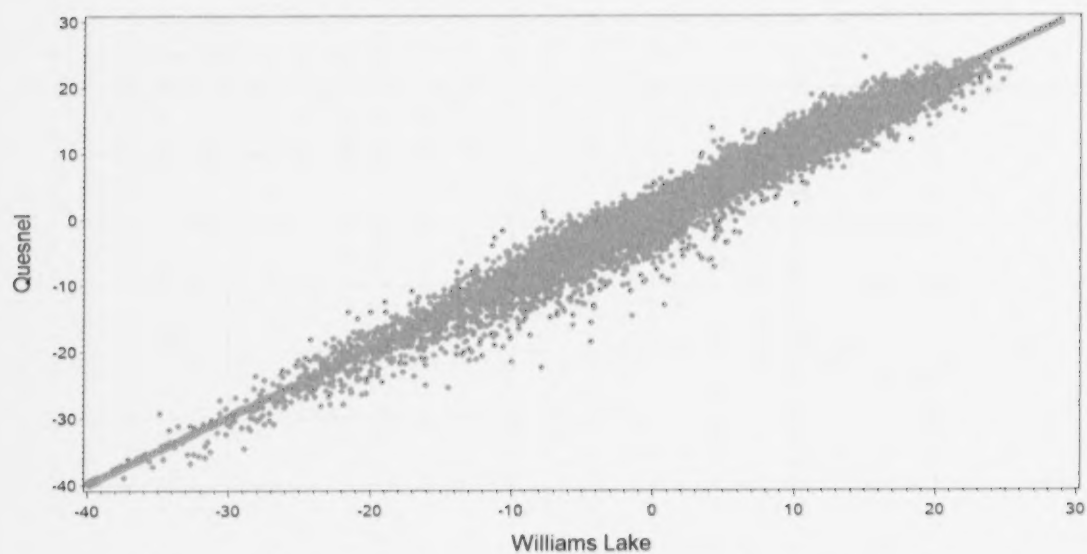
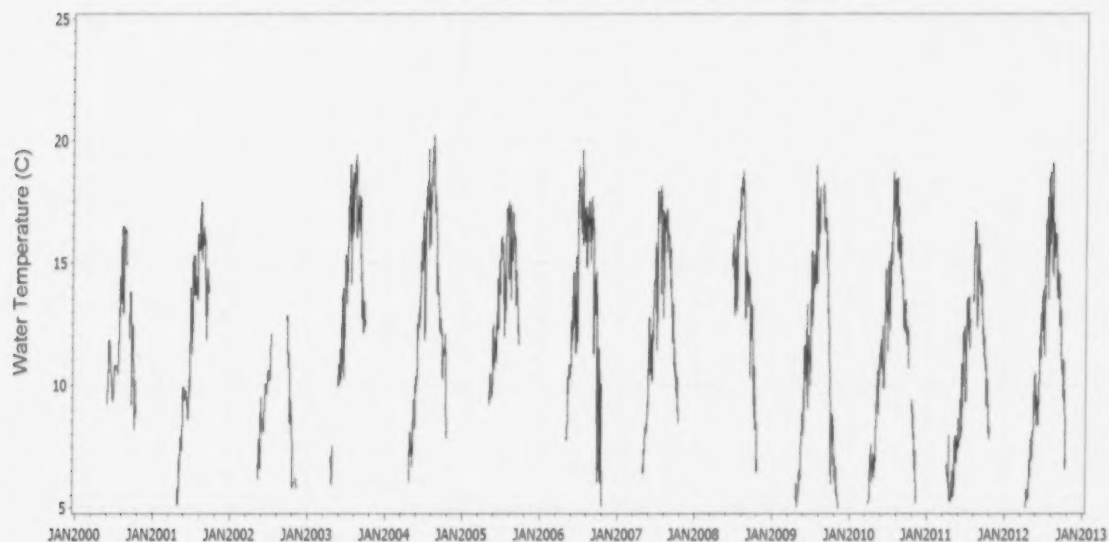


Figure 31. QUESNEL daily air temperature as a function of regional AHCCD station air temperature at WILLIAMS LAKE ($r = 0.92$; $P = 0.001$; $n > 3,000$).

Quesnel Water Temperature Observations



Quesnel Water Temperature Observations (WSC)

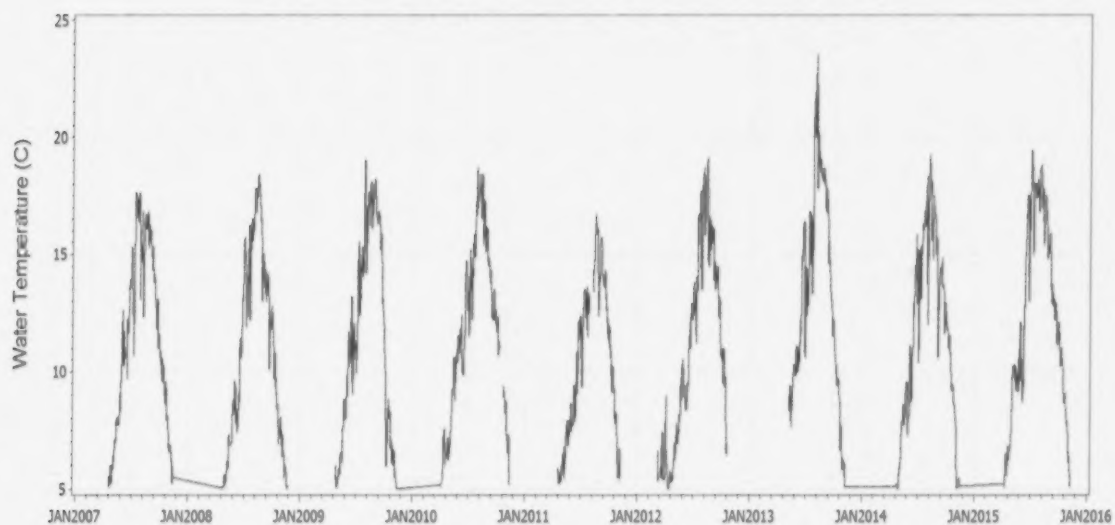


Figure 32. Lower Quesnel River daily water temperature observations. Source: DFO ENVIRONMENTAL WATCH PROGRAM station QR-1, 2000-2012 (top), and ECCC WATER SURVEY OF CANADA station 08KH006, 2007-2015 (bottom).

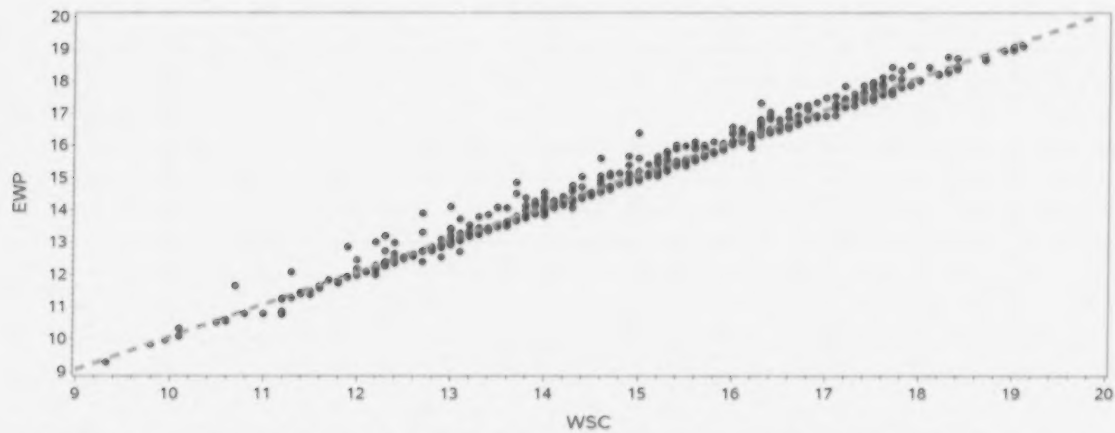


Figure 33. Lower Quesnel River daily mean water temperature observations (at EWP station QR-1) as a function of lower QUESNEL RIVER (WSC station 08KH006), July-August-September, 2006-2012 ($r = 0.98$; $P < 0.001$; $n=557$; $a=0.0017$; $b=1.007$). Intercept is not significantly different from zero; slope is not significantly different from 1.

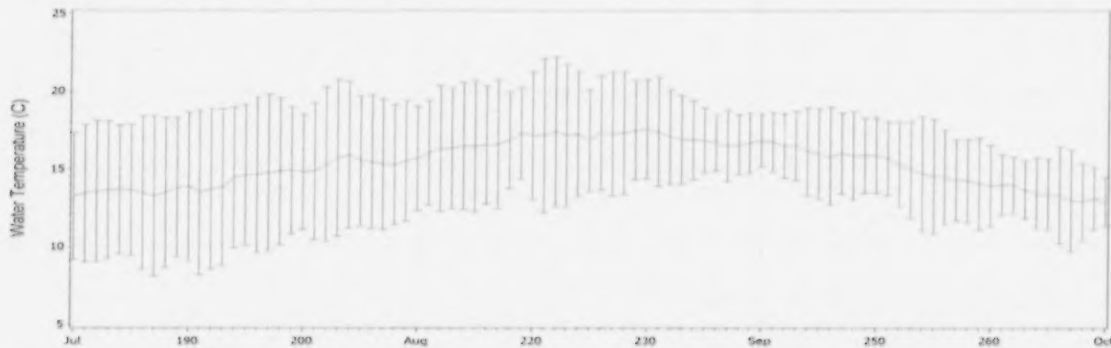


Figure 34. Summer month thermograph of mean daily water temperature $\pm$ two standard deviations for lower Quesnel River daily water temperature. Based on observed and estimated data, 2000-2001, 2003-2015.

Horsefly Water Temperature Observations

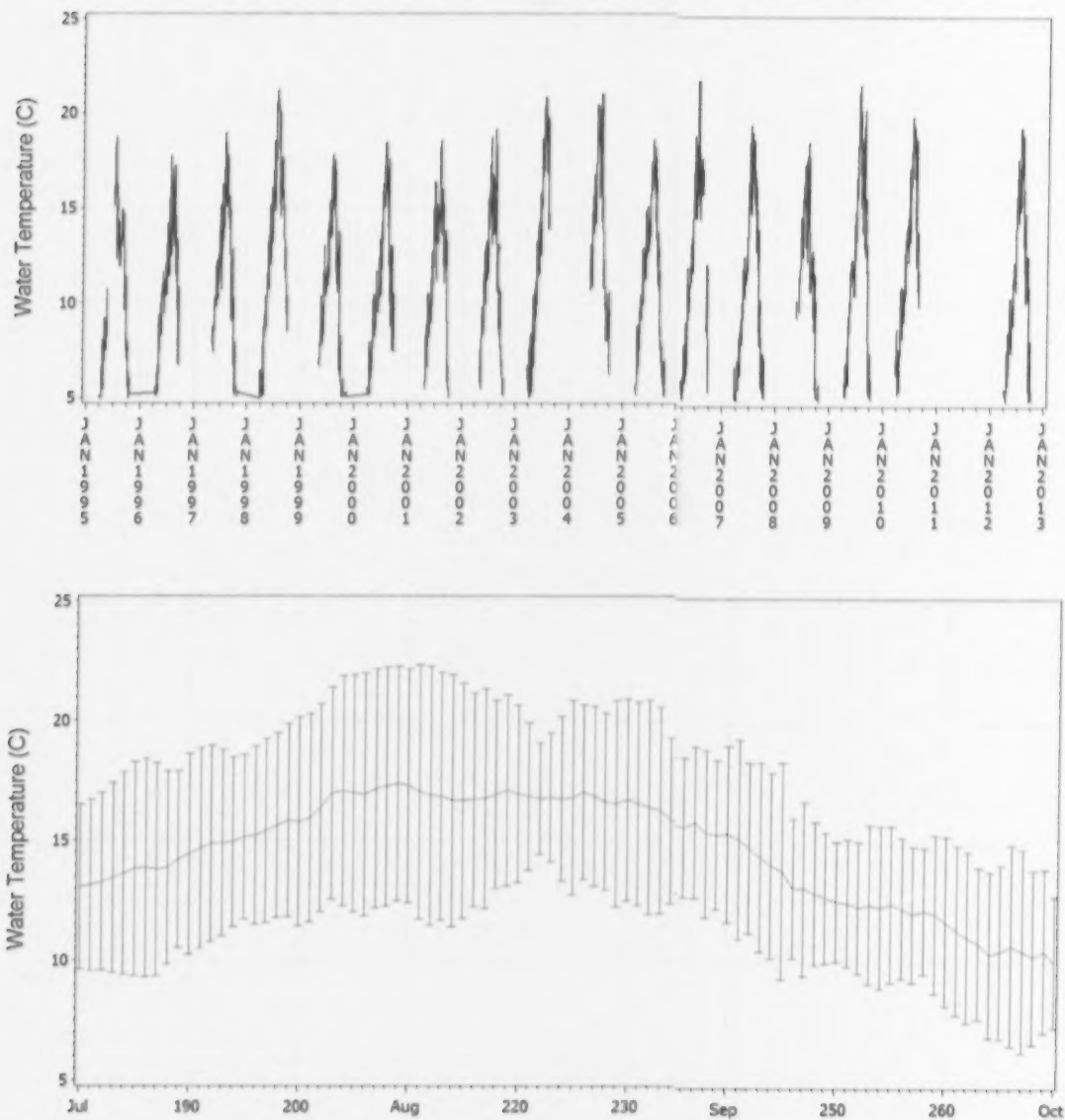


Figure 35. HORSEFLY RIVER (EWP station HR-22) daily water temperature observations (top) and annual thermograph of mean water temperature $\pm$ two standard deviations (bottom), 1995-2010, 2012. (Source: DFO STOCKASSESSMENT & ENVIRONMENTAL WATCH PROGRAM).

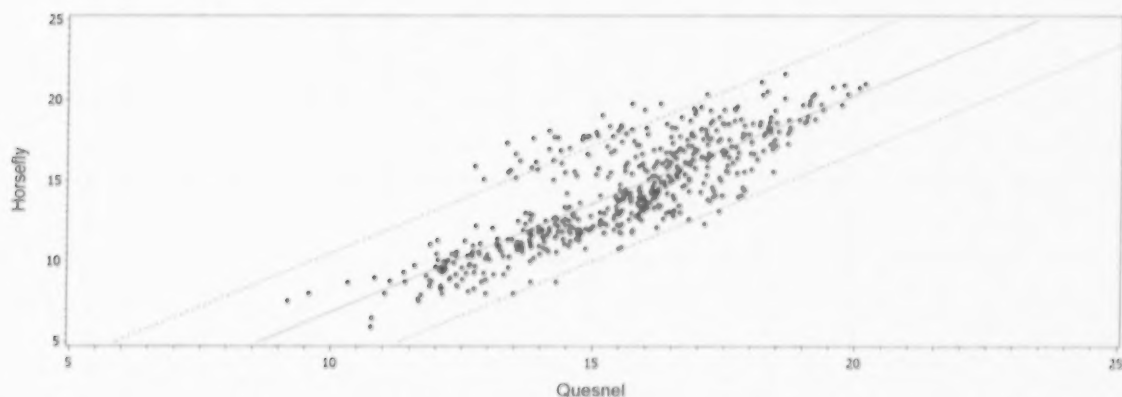


Figure 36. HORSEFLY RIVER (HR-22) daily mean water temperature observations as a function of QUESNEL RIVER (QR-1), August-September, 1995-2012 ($r = 0.80$; $P < 0.001$; $n=557$; $a=-6.60$; $b=1.35$).

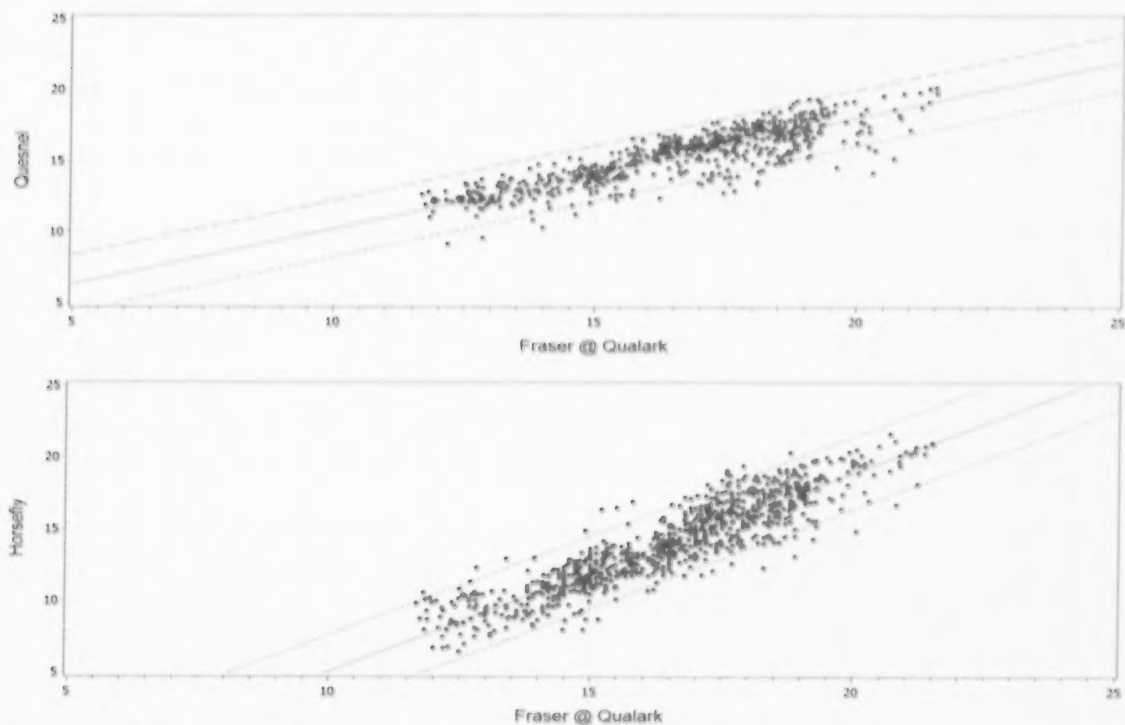


Figure 37. Daily mean water temperature observations at QUESNEL RIVER (QR-1; BOTTOM; $r = 0.85$; $P < 0.001$; $n=630$; $a=2.45$; $b=0.78$) and HORSEFLY RIVER (HR-22; TOP; $r = 0.91$; $P < 0.001$; $n=891$; $a=-8.7$; $b=1.38$) as a function of FRASER RIVER (AT QUALARK), August-September, 1995-2012.

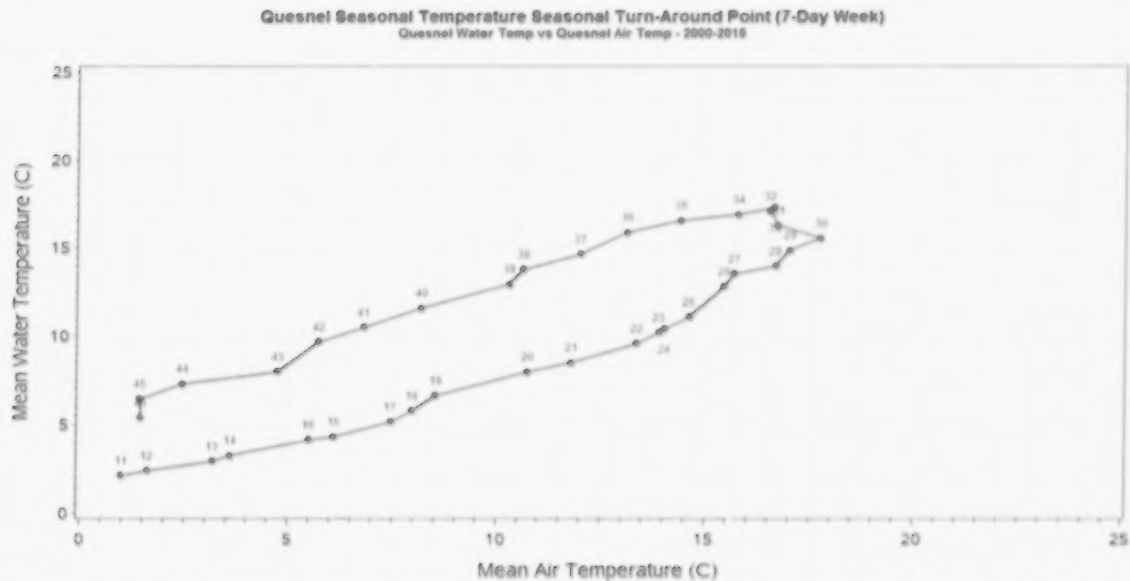


Figure 38. Derivation of seasonal turn-around point for lower QUESNEL RIVER (near Quesnel), based on maximum weekly mean air and water temperature data. The seasonal turn-around point was week 30 (day 210), approximately August 2nd. The "warming season" therefore extends from April 1st to August 2nd, followed by the "cooling season" from day 211-329, i.e. August 3rd - November 25th.

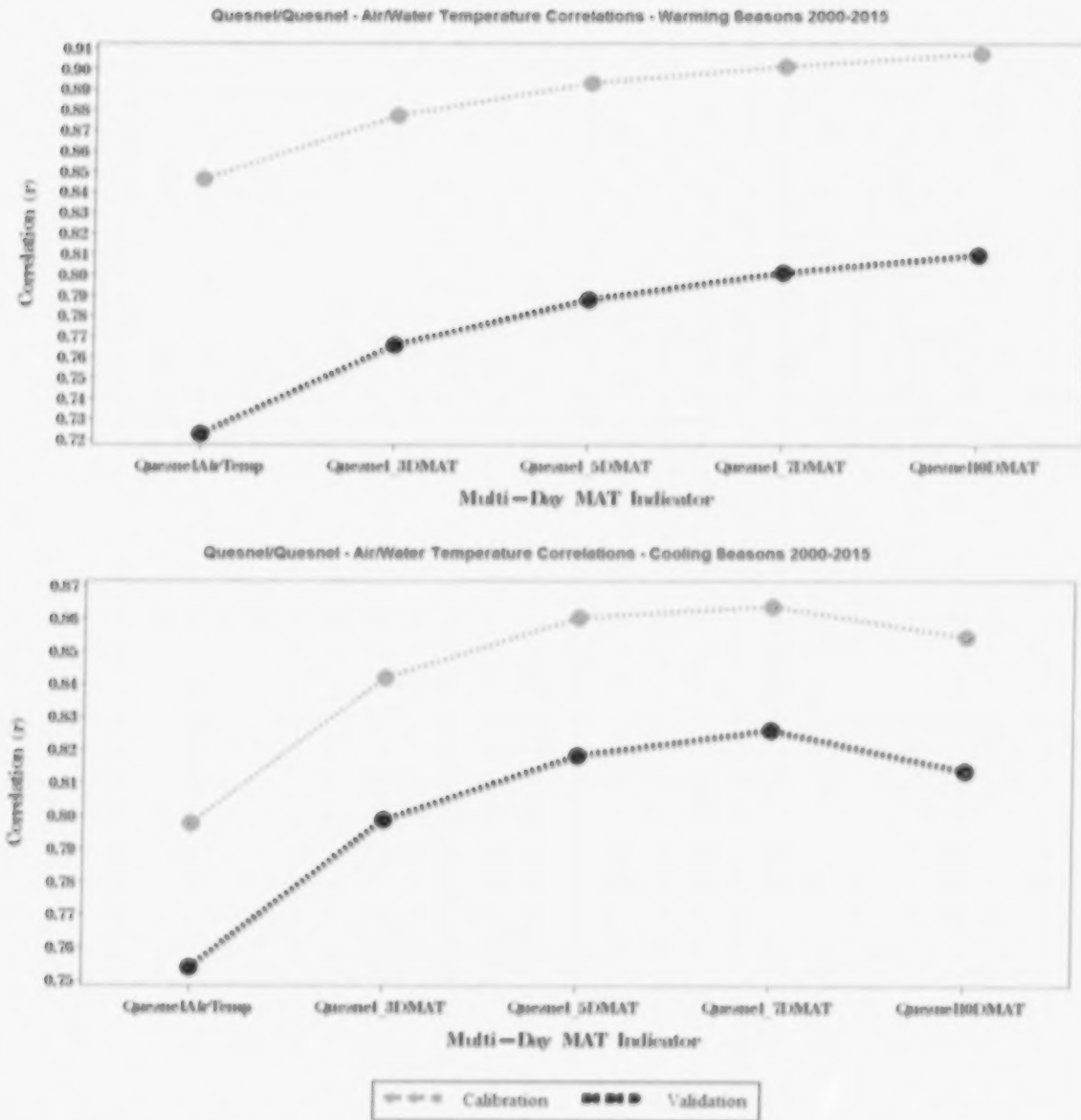


Figure 39. Derivation of optimum regional air temperature index for air/water temperature analyses, based on maximum all-year correlation between various QUESNEL multi-day mean air temperature indicators (MATs) with lower QUESNEL RIVER daily mean water temperature (MWT) for calibration (red) and validation data; warming season (top), cooling season (bottom). QUESNEL air temperature indicators include (l-r): QUESNELAIRTEMP (same day mean); QUESNEL 3-day centered moving average air temperature (3d-MAT), 5d-MAT, 7d-MAT, and 10d-MAT.

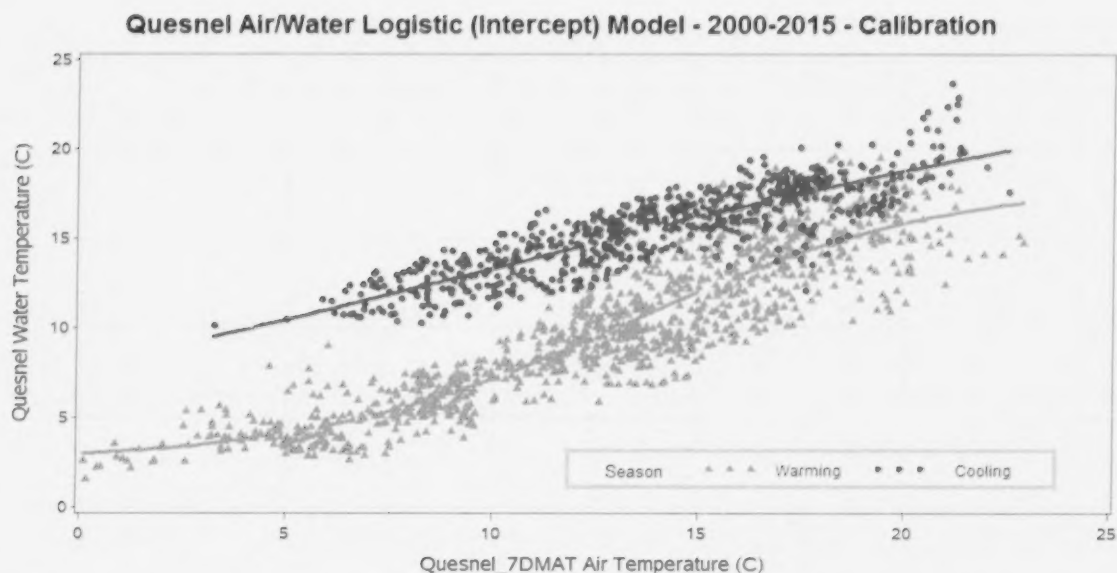


Figure 40. Logistic regression fits for air/water temperature relationship for lower QUESNEL RIVER daily mean water temperatures as a function of the QUESNEL 7d-MAT (centered moving air temperature index) for calibration data years (see Table 11) by season (warming season: red; cooling season: blue).

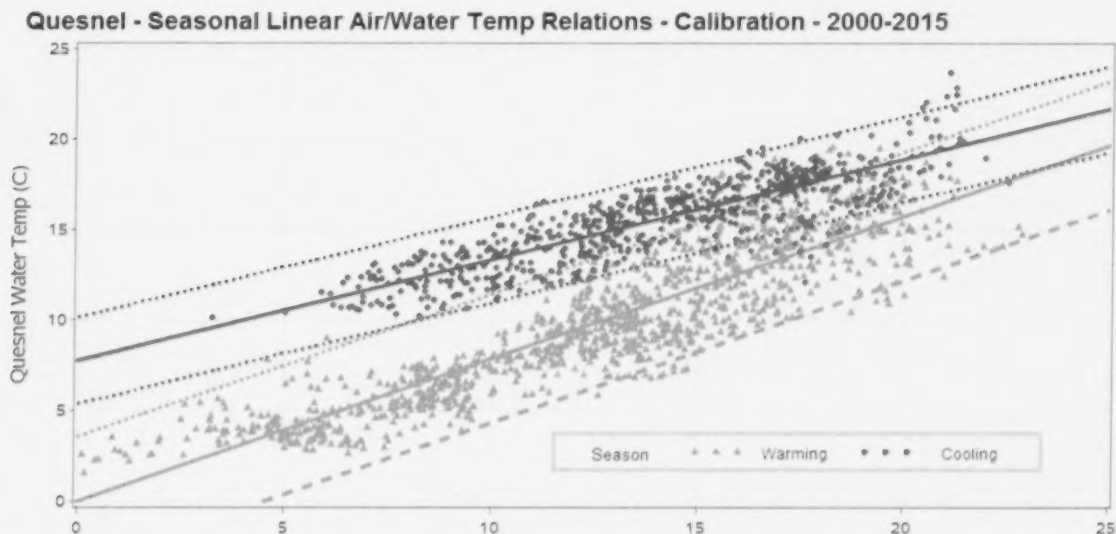


Figure 41. Linear regression fits for air/water temperature relationship for lower QUESNEL RIVER daily mean water temperatures as a function of the QUESNEL 7d-MAT (centered moving air temperature index) for calibration data years (see Table 11), by season (warming season: red; cooling season: blue).

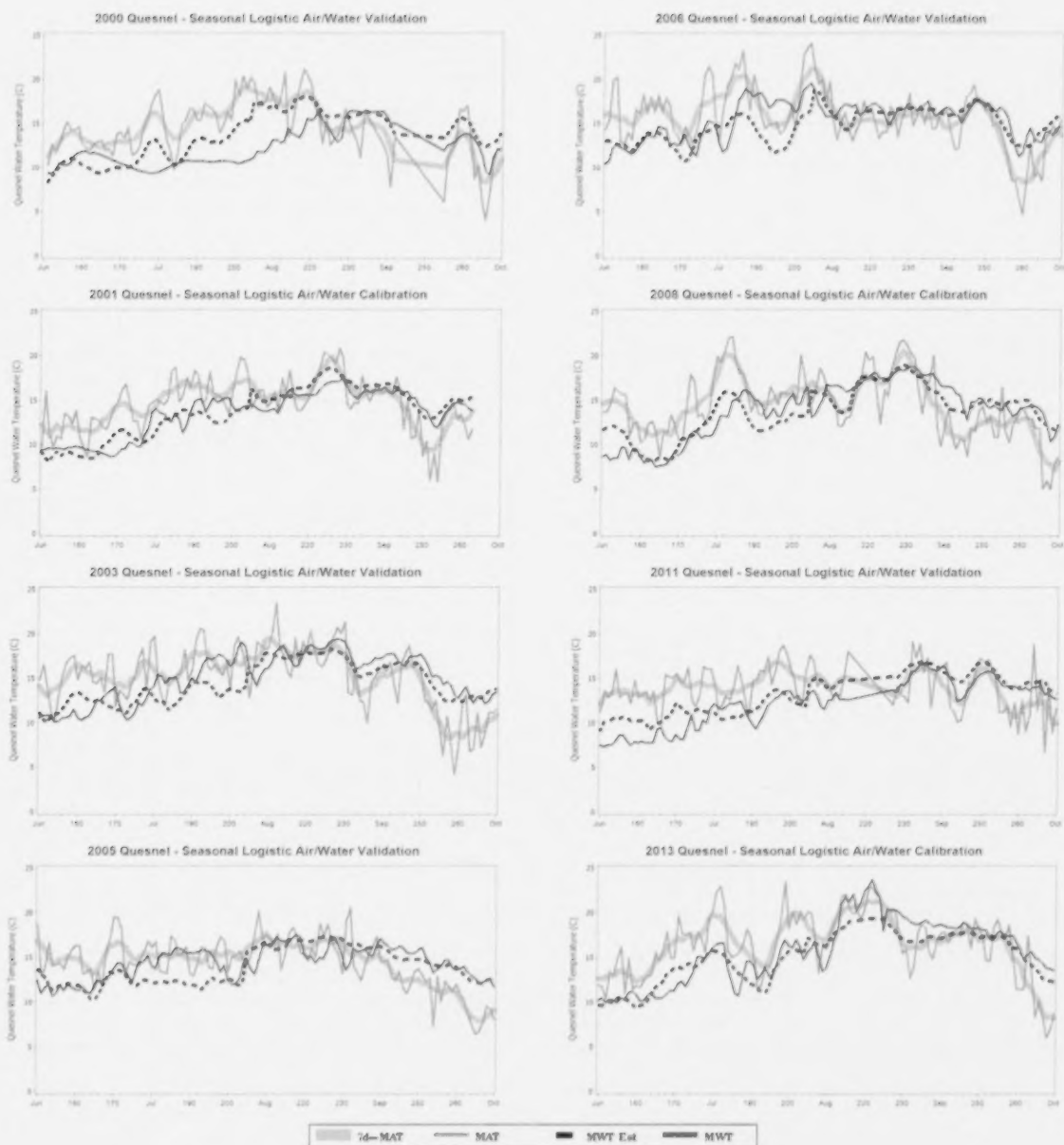


Figure 42. Validation plots of logistically-estimated daily mean water temperature (MWT; black dashed line) daily mean air temperature (red line), 7-day MAT index (broad pink line), observed daily mean water temperature (blue solid line) and for lower QUESNEL RIVER.

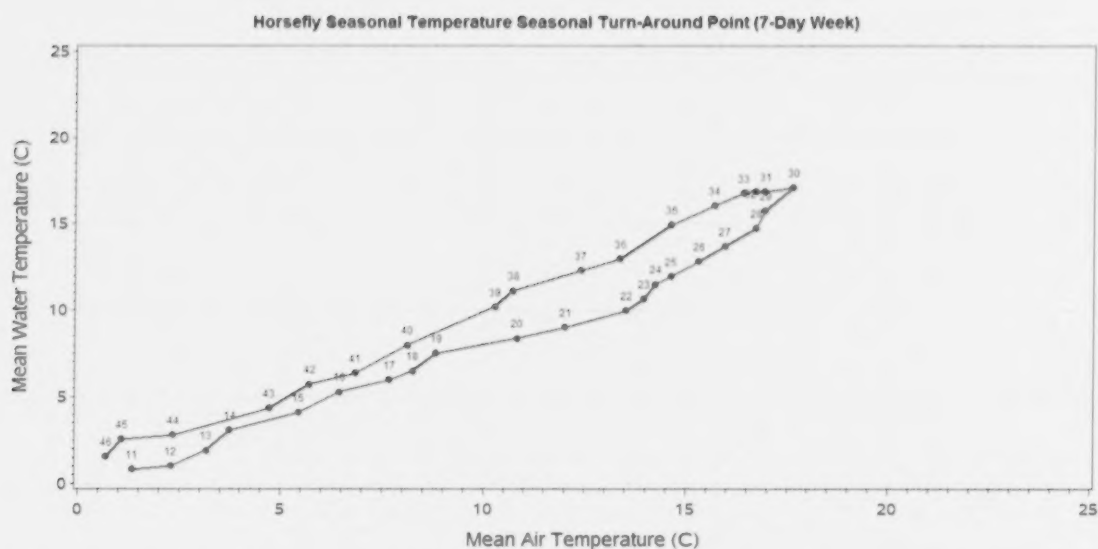


Figure 43. Derivation of seasonal turn-around point for Horsefly River, based on maximum weekly mean air and water temperature data. The seasonal turn-around point was week 30 (day 210), approximately August 2nd. The "warming season" therefore extends from April 1st to August 2nd, followed by the "cooling season" from day 211-329, i.e. August 3rd - November 25th.

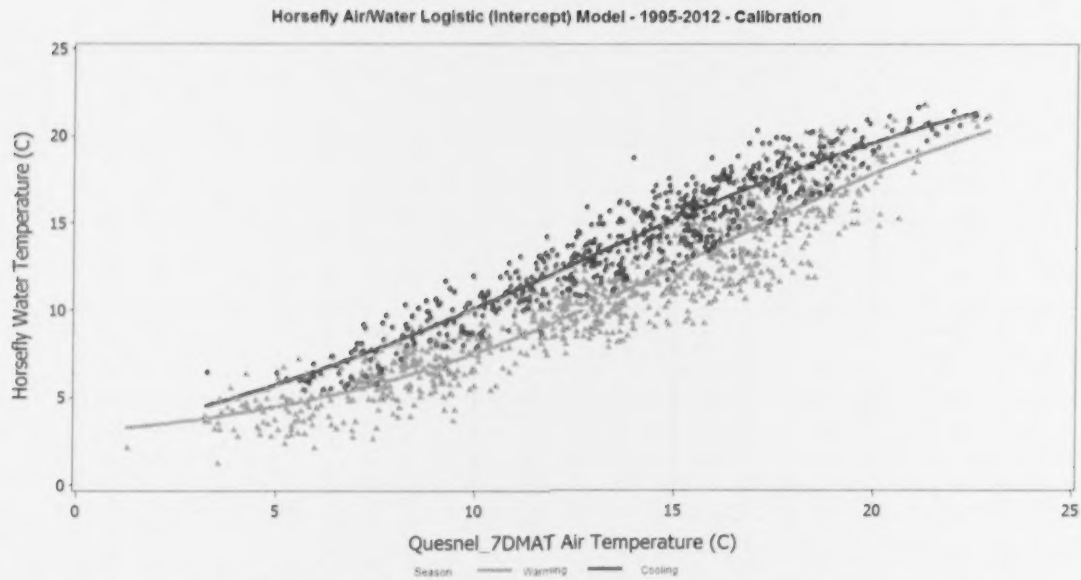


Figure 44. Logistic regression fits for air/water temperature relationship for HORSEFLY RIVER daily mean water temperatures as a function of the QUESNEL 7d-CMAT (air temperature index) for calibration data years (see Table 17) by season (warming season: red; cooling season: blue).

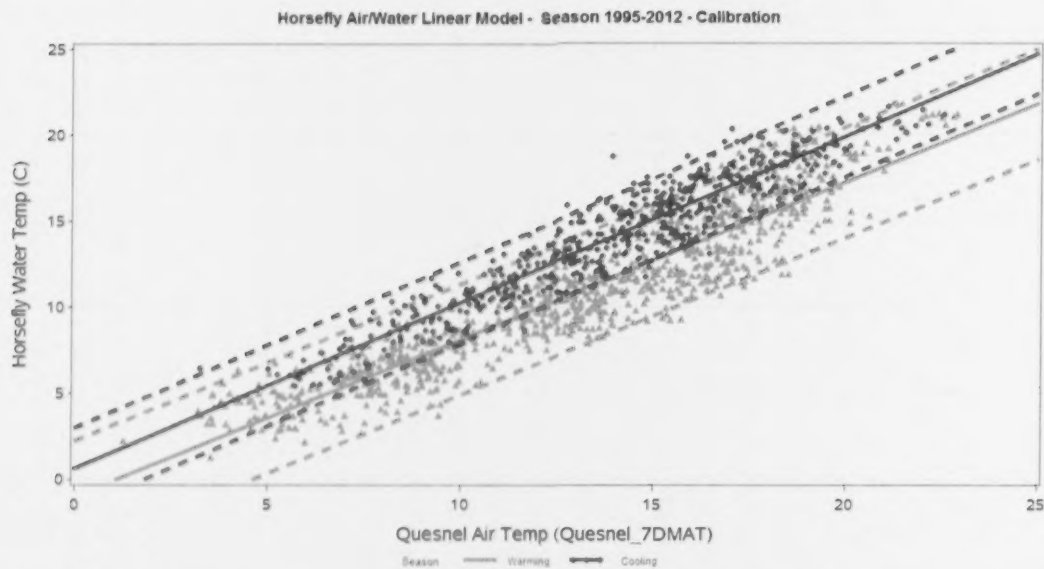


Figure 45. Linear regression fits for air/water temperature relationship for HORSEFLY RIVER daily mean water temperatures as a function of the QUESNEL 7d-CMAT (air temperature index) for calibration data years (see Table 17), by season (warming season: red; cooling season: blue).

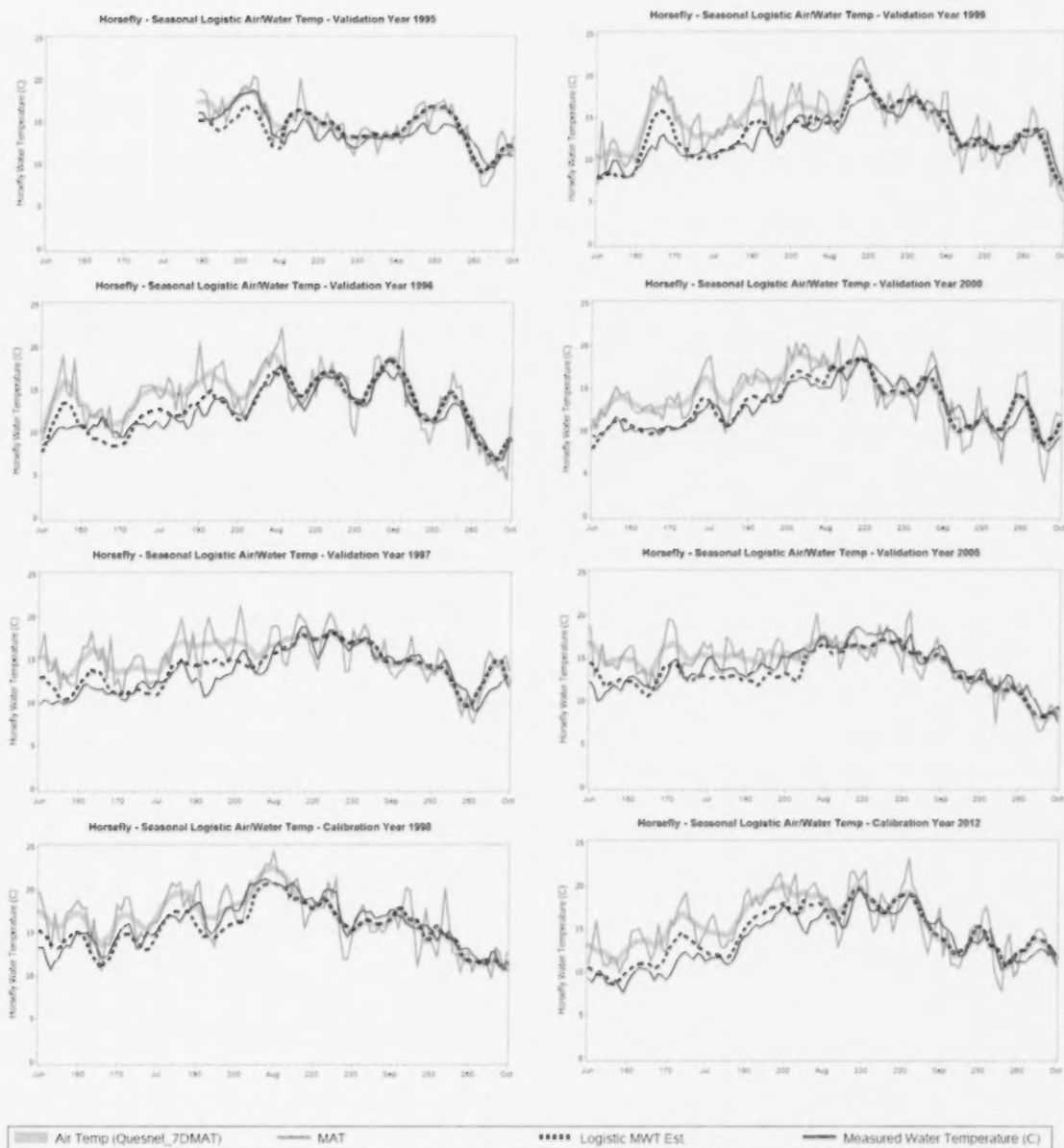


Figure 46. Sample plots of daily mean air temperature (red line), 7-day MAT index (broad pink line), observed daily mean water temperature (blue solid line) and estimated MWT (black dashed line; based on seasonal logistic regression models) for HORSEFLY RIVER, June-September.

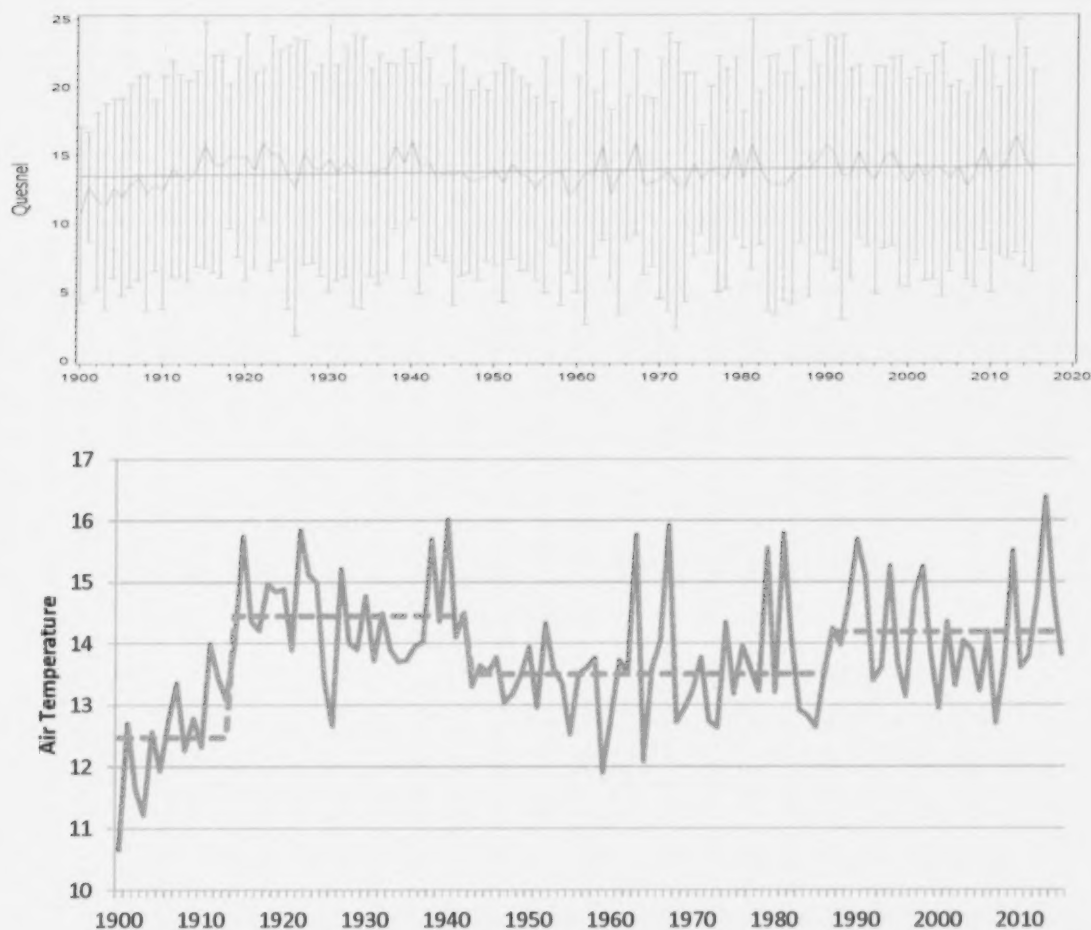


Figure 47. Observed and estimated QUESNEL AHCCD station mean seasonal air temperature $\pm$ 2 std deviations, August-September 1900-2015 (top). Weak long-term warming trend is evident ($Y = 0.76 + 0.007 * \text{Year}$; $r = 0.00$; $P < .001$). Regime shift detection in mean air temperature, 1900-2015 (bottom), after prewhitening, target $p = 0.05$, cutoff length=20 years, tuning constant=2, $AR(1)=0.06$ (IP4), subsample size=12 years.

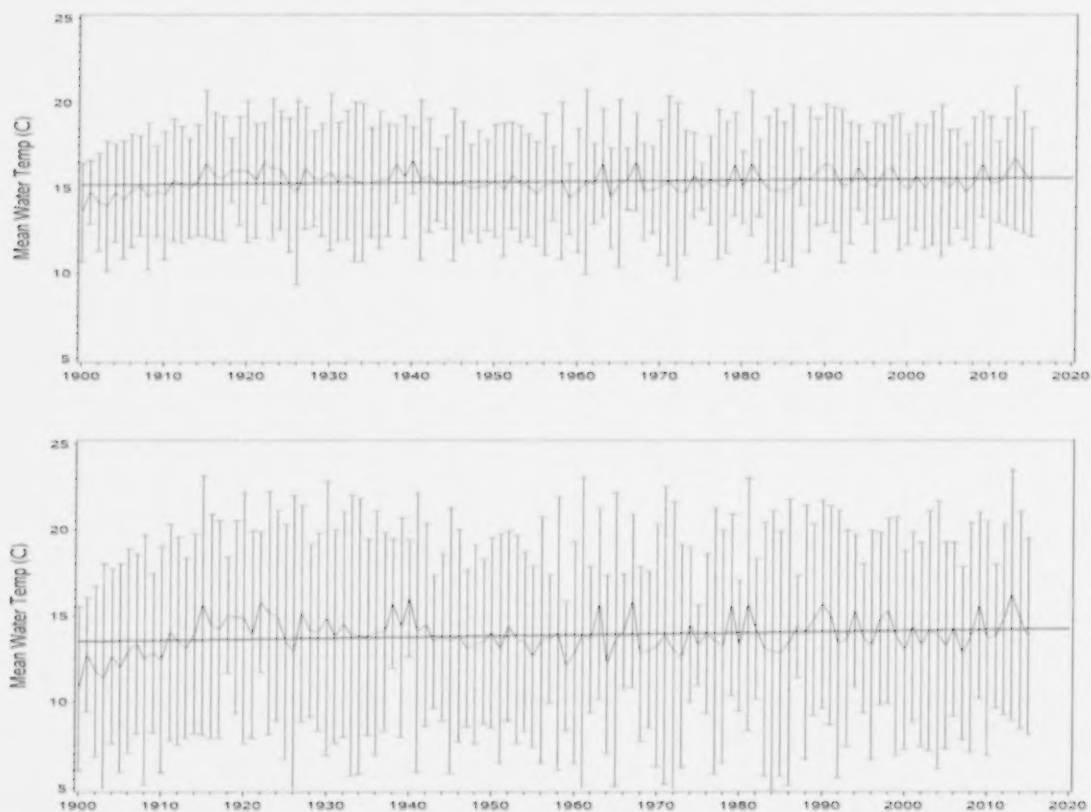


Figure 48. Estimated mean seasonal water temperature ± 2 std deviations, August-September 1900-2015, based on seasonal logistic air/water temperature regression models (lower QUESNEL RIVER, top; lower HORSEFLY RIVER, bottom).

Lower Quesnel River Discharge

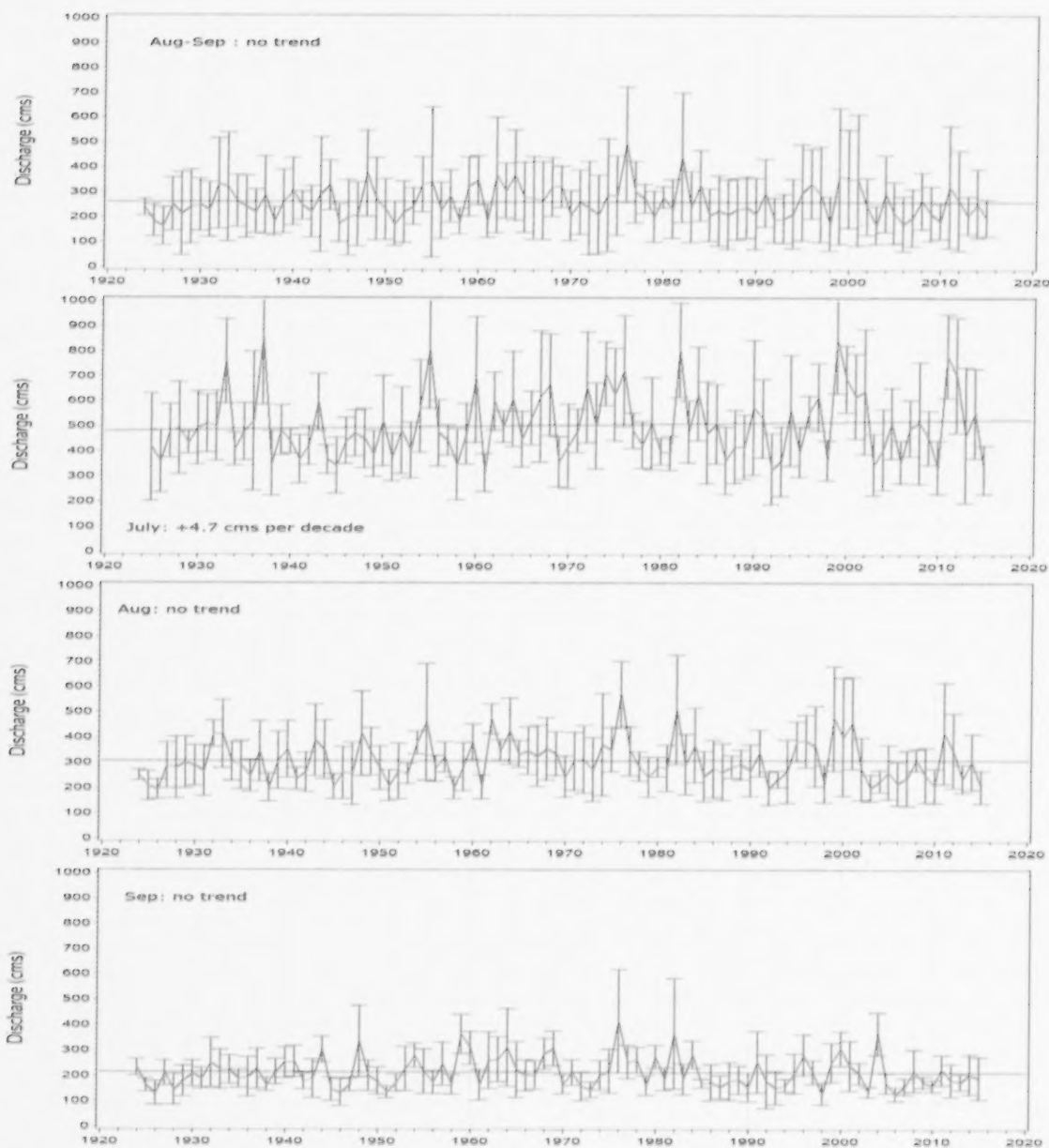


Figure 49. Observed plus estimated lower QUESNEL RIVER mean discharge (± 2 standard deviations), 1924-2015. No significant trends during months of migration.

Lower Horsefly River Discharge

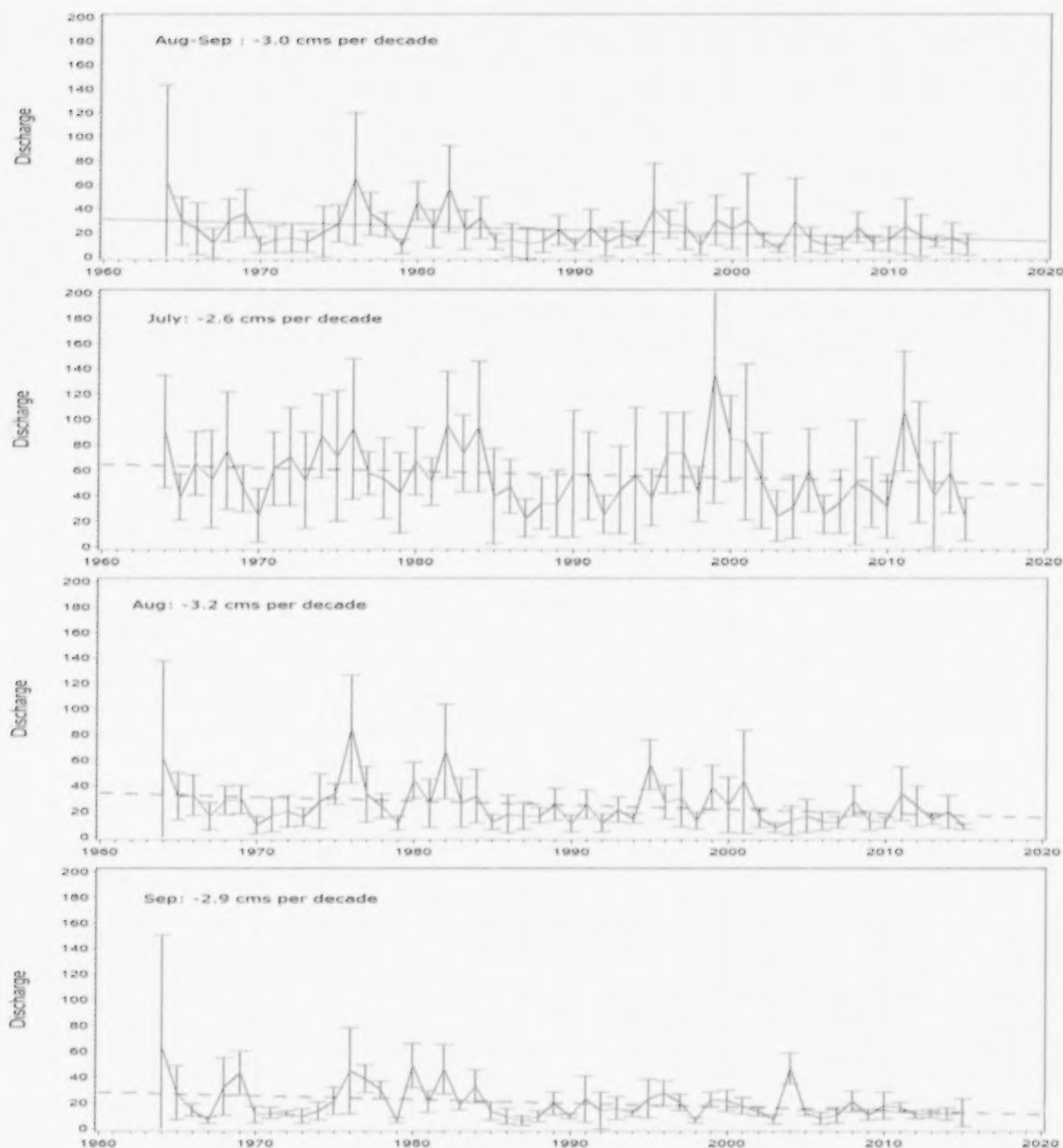


Figure 50. Trends in observed and estimated lower HORSEFLY RIVER mean summer discharge ± 2 standard deviations, 1964-2015. Summer seasonal discharge (combined August-September; top) shows significant negative trend ($P < 0.001$); August shows strongest negative trend.

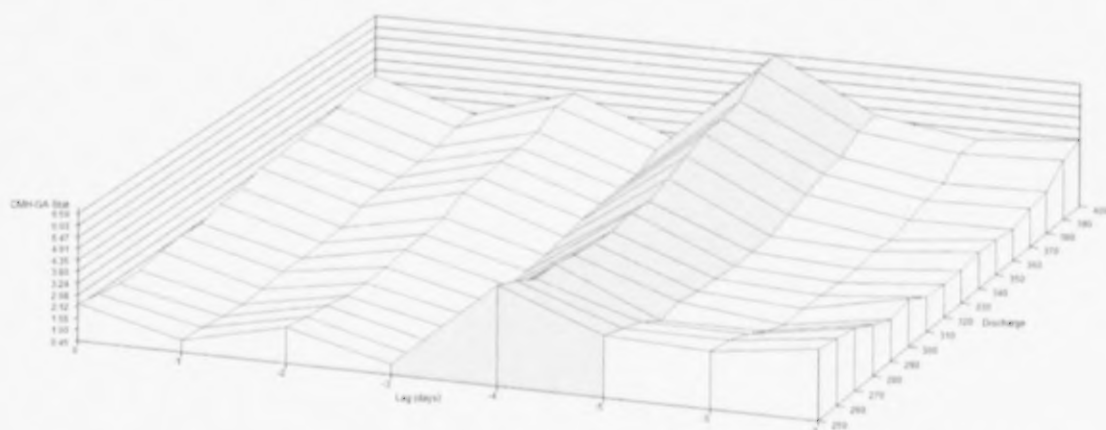


Figure 51. Distribution of the *CMH-GA chi-square* test statistic for association of high/low daily migration categories (based on combined upper Quesnel visual and acoustic count data) in relation to lower Quesnel River water temperature categories (Low $\leq 17^{\circ}\text{C}$; high $>17^{\circ}\text{C}$) stratified by discharge⁸². Large differences in Sockeye migration were most strongly associated with discharge levels ranging from 260-270 and >340 cms occurring 4 days before reaching the counter site (shaded areas; $P < 0.05$).

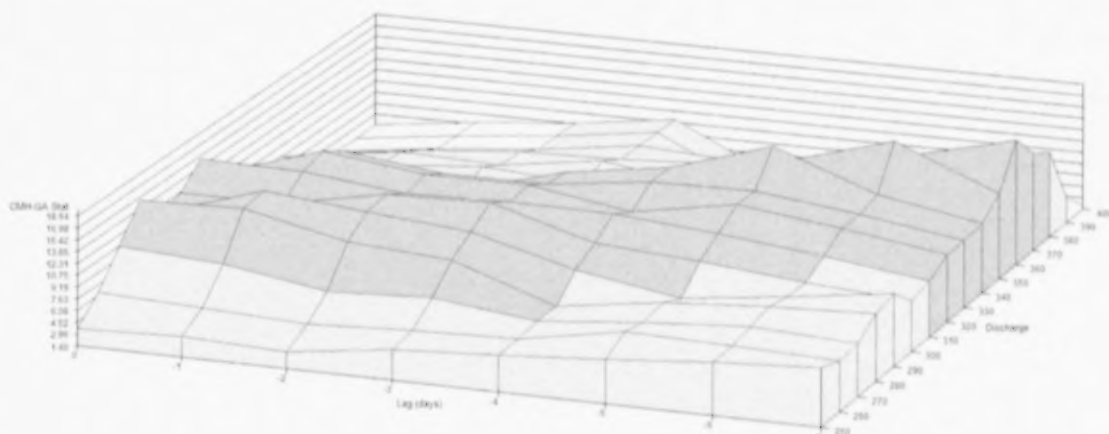


Figure 52. Distribution of the *CMH-GA* test statistic for association of high/low daily migration categories (combined upper Quesnel visual and acoustic count data in relation to lower Quesnel discharge categories stratified by water temperature categories (Low $\leq 17^{\circ}\text{C}$; high $>17^{\circ}\text{C}$). Large differences in Sockeye migration were most strongly associated with discharge levels ranging from 280 cms 2-3 days prior to 340-350 cms 4-6 days prior to enumeration (dark shaded areas; $P < 0.001$; light shaded areas; $P < 0.05$).

⁸² Test-statistic was generated for a range of migration date time lags (0-7 days) for a range of discharge thresholds (250-400 cms) while holding the water temperature threshold constant (17°C).

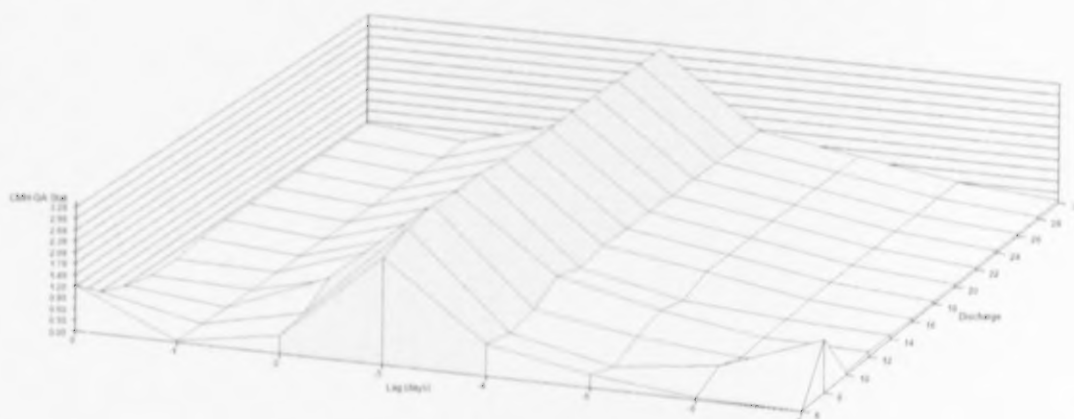


Figure 53. Distribution of the *CMH-GA chi-square* test statistic for association of high/low Horsefly daily migration categories (based on acoustic count data in the Horsefly River) in relation to lower Horsefly River water temperature categories (Low $\leq 15^{\circ}\text{C}$; high $>15^{\circ}\text{C}$) stratified by discharge⁸³. Differences in Sockeye migration were weakly associated with water temperature categories three days before reaching the counter site (shaded areas; $0.05 < P < 0.10$).

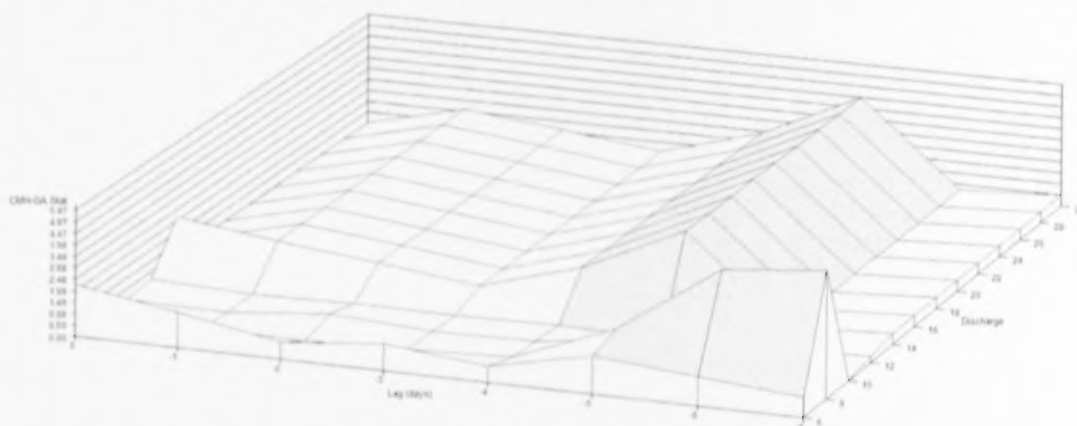


Figure 54. Distribution of the *CMH-GA* test statistic for categorization of high/low Horsefly migration categories (based on acoustic count data in the Horsefly River) in relation to lower Horsefly River discharge levels, stratified by water temperature threshold (15°C). Significant differences in Sockeye migration were associated with discharge categories at very low discharge levels (~ 8 cms) 6-7 days before reaching the counter site, and across a range of higher discharge levels (14-30 cms) four days prior (shaded areas: $P < 0.05$).

⁸³ Test-statistic was generated for a range of migration date time lags (0-7 days) for a range of discharge (6-30 cms) and water temperature thresholds (13 - 18°C), while holding the water temperature threshold constant. Output displayed only for 15°C threshold.

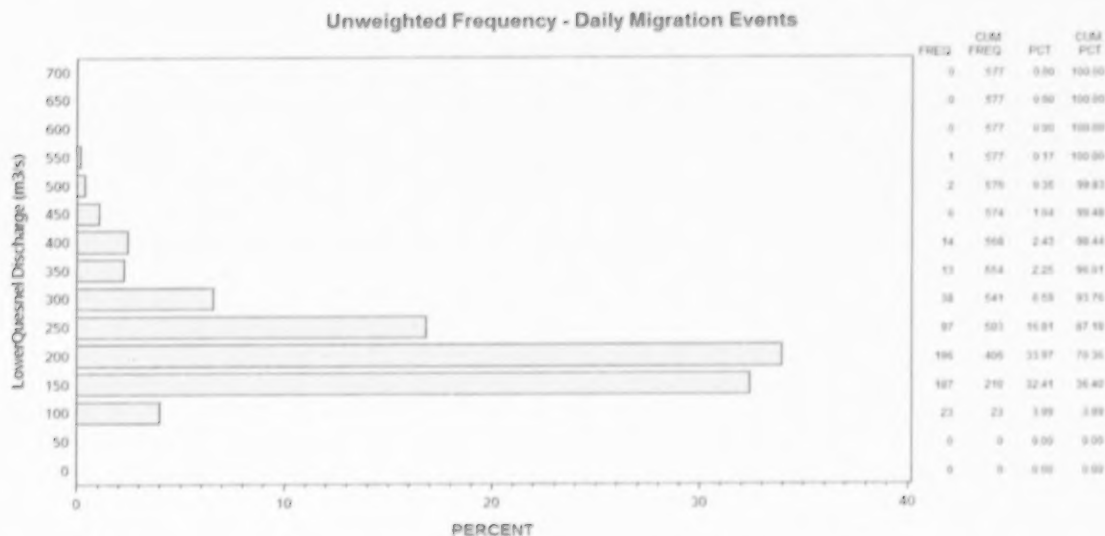


Figure 55. Frequency plot of historical Sockeye migration (un-weighted tally of non-zero migration dates), at varying levels of lower Quesnel River discharge 4 days earlier. Most dates (77%) of migration occurred when flows in the Quesnel four days earlier were ~150-250 cms.

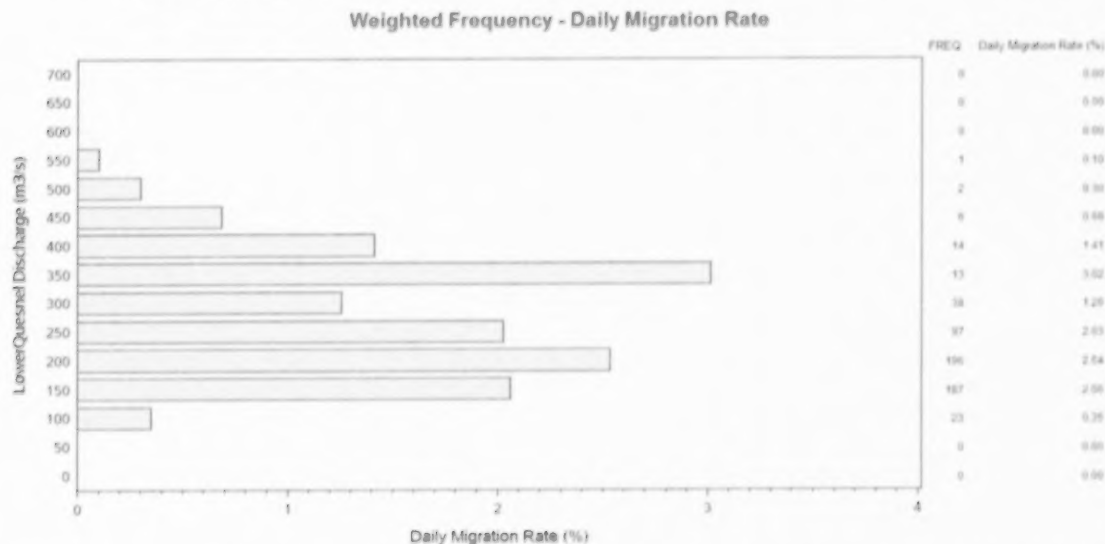


Figure 56. Frequency plot of historical Sockeye non-zero migration dates, weighted by daily migration rate, at varying levels of lower Quesnel River discharge 4 days earlier. Moderate daily migration rates (>1.6%) occurred at a narrow range of discharge levels (150-250 cms), with highest rates at 350 cms.

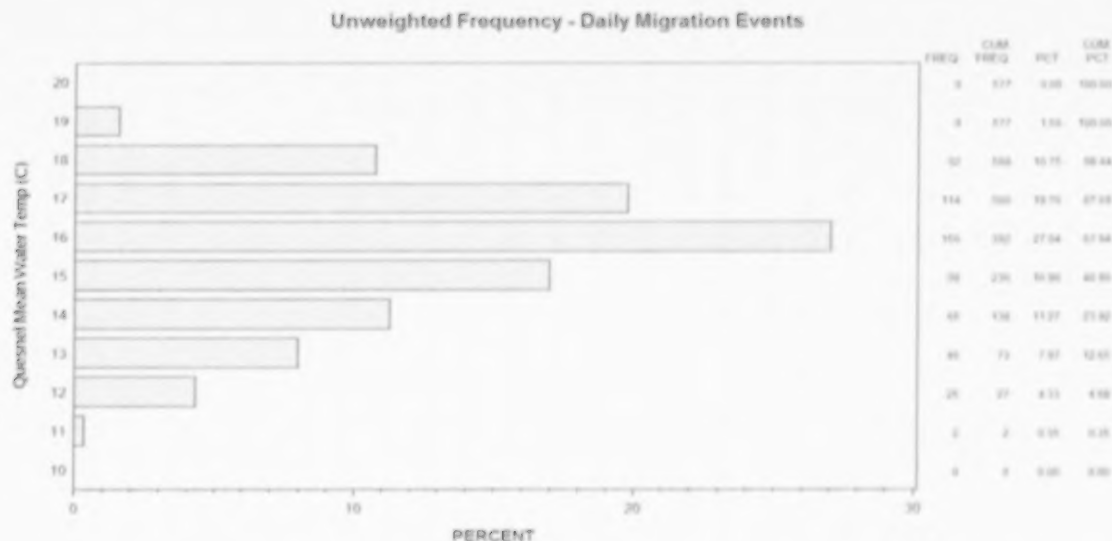


Figure 57. Frequency plot of historical Sockeye migration (un-weighted tally of non-zero migration dates), at varying levels of lower Quesnel River water temperature 4 days earlier. ~75% of migration activity occurred at estimated temperatures of 15-17°C.

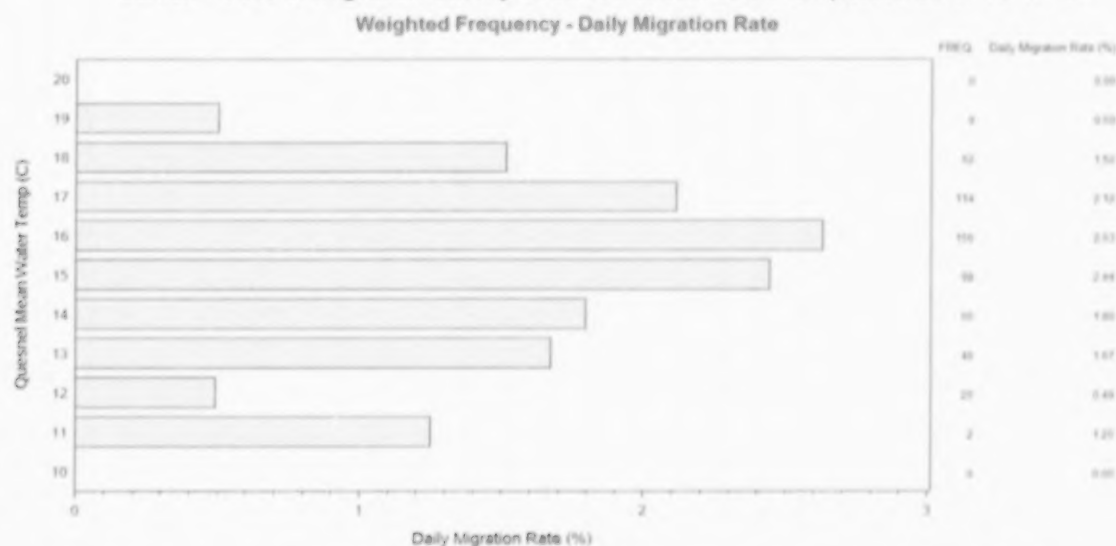
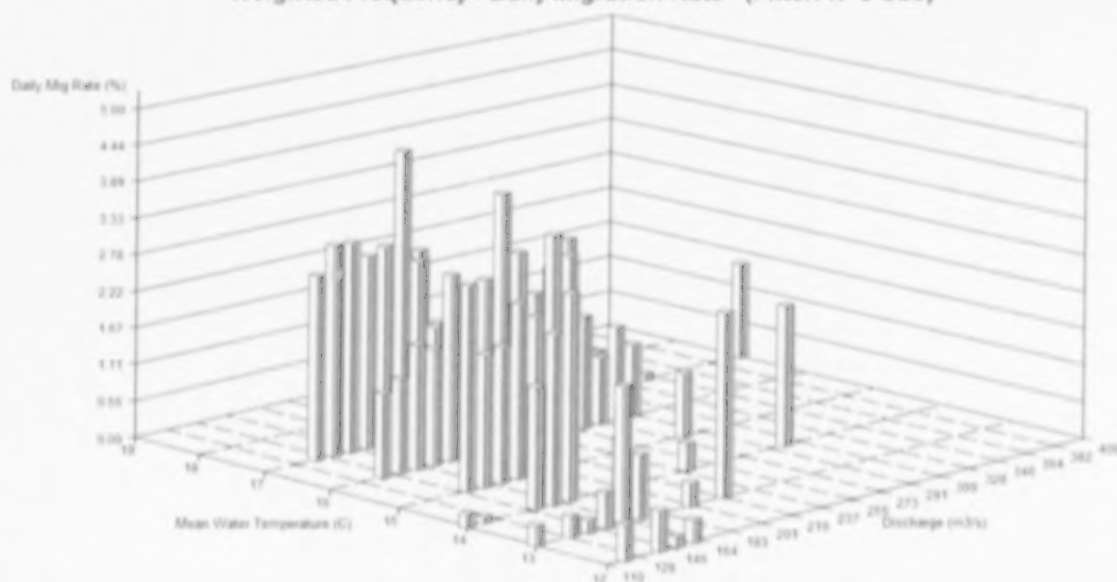


Figure 58. Frequency plot of historical Sockeye non-zero migration dates, weighted by daily migration rate, at varying levels of lower Quesnel River water temperature 4 days earlier. Highest mean daily migration rates were associated with estimated water temperatures of 15-17°C.

Weighted Frequency - Daily Migration Rate - (Filter: N>3 Obs)



Weighted Frequency - Daily Migration Rate - (Filter: N>3 Obs)

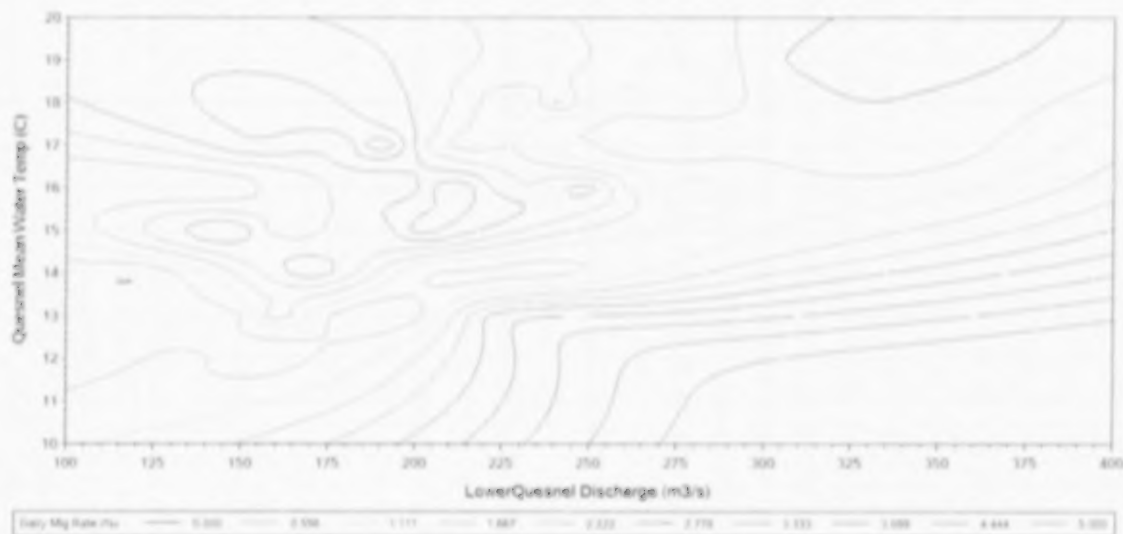


Figure 59. Weighted frequency distribution (top) and smoothed contour (bottom) of historical Sockeye migration rates (daily %), at varying levels of lower Quesnel River water temperature and discharge 4 days earlier (filtered for a minimum of 3 observations at each temperature x flow point). Moderate-to-high migration rates (>3%) were found at a wide range of discharge and temperature levels, with maxima at 15-17°C and 150-250 cms.

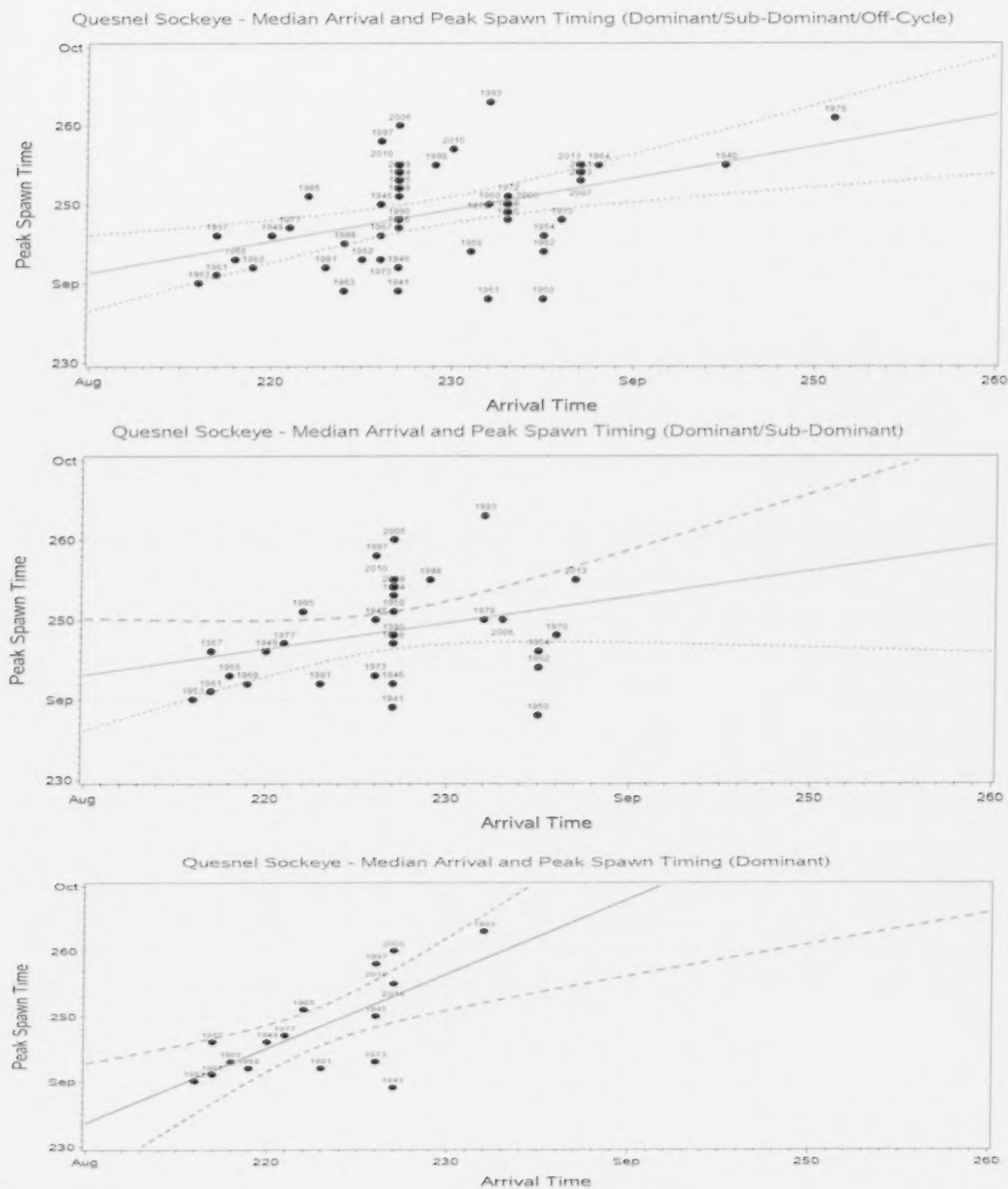


Figure 60. Annual date of peak spawning activity as a function of annual date of arrival of adult Sockeye on the Horsefly River spawning grounds, 1940-2015 (Dominant cycle line years only: $r^2 = 0.47$; $a = -6.9$; $b = 1.14$; $P < 0.005$, $n = 17$).

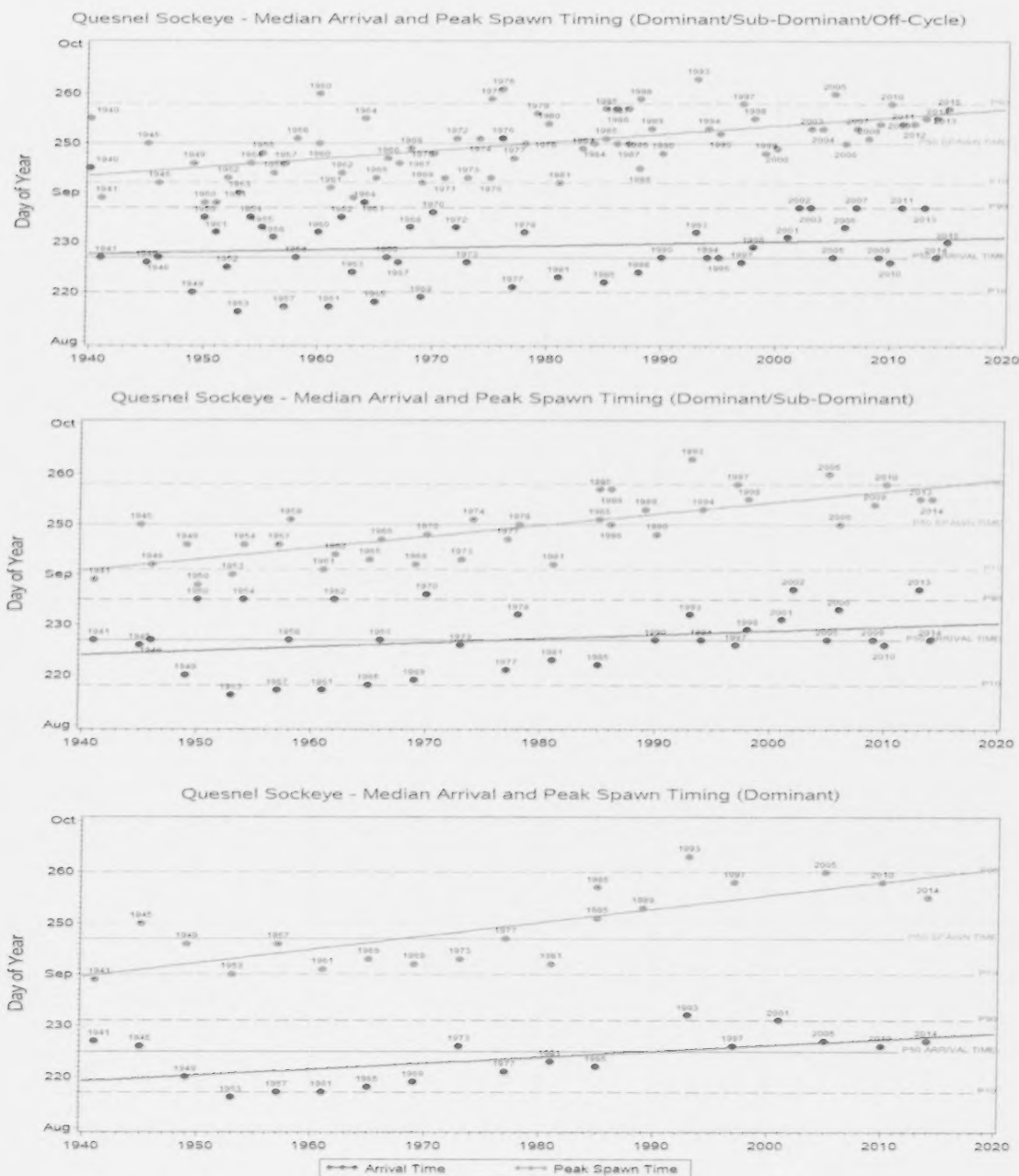


Figure 61. Annual date of arrival of adult Sockeye on the Horsefly River spawning grounds (blue) and median date of peak spawning activity (red), 1941-2014 (top: all cycle lines; middle: dominant and sub-dominant cycle lines only; bottom: dominant cycle line only). Solid horizontal lines show all-year median (50th percentile); dashed lines indicate 10th and 90th percentiles. Positive time trends are indicated (Arrival Time: $r^2 = 0.21$, $P = 0.07$; Peak Spawning Time: $r^2 = 0.56$, $P < 0.001$).

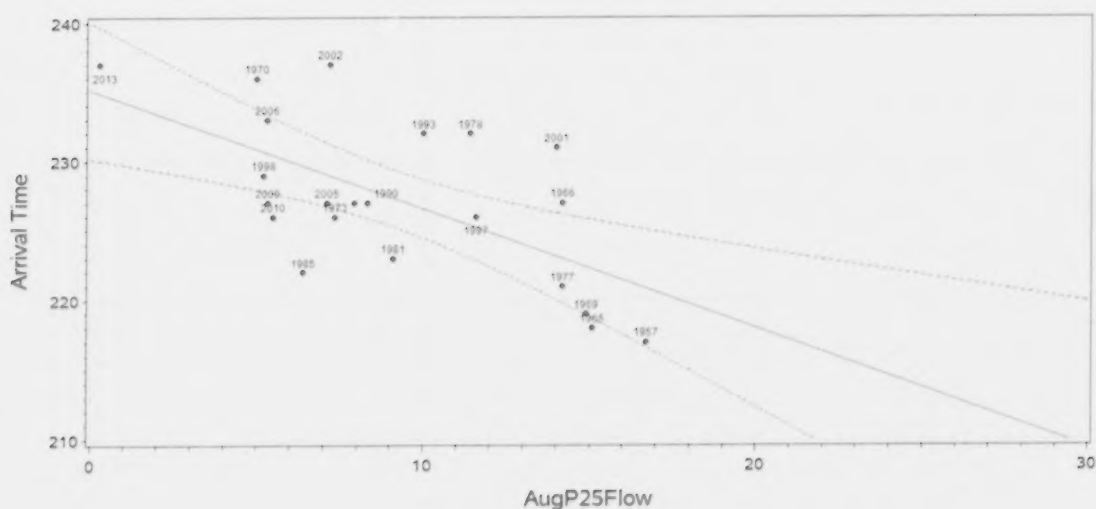


Figure 62. Annual date of arrival of adult Sockeye on the Horsefly spawning grounds as a function of Horsefly River 25th percentile of daily discharge in August ($r^2 = 0.40$; $P = 0.0017$, $n = 22$).

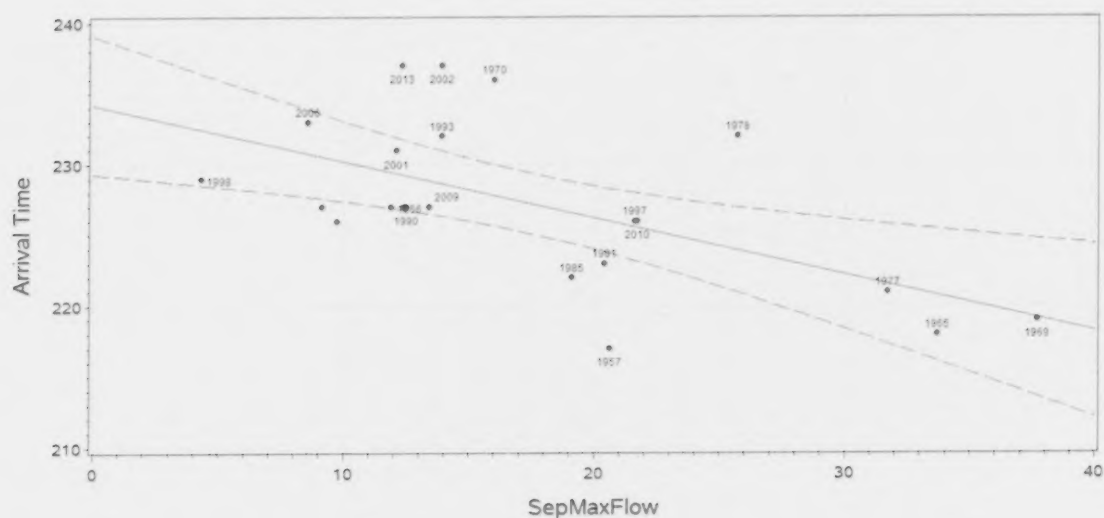


Figure 63. Annual date of arrival of adult Sockeye on the Horsefly spawning grounds as a function of Horsefly River maximum daily discharge in September ($r^2 = 0.35$; $P = 0.0037$, $n = 22$).

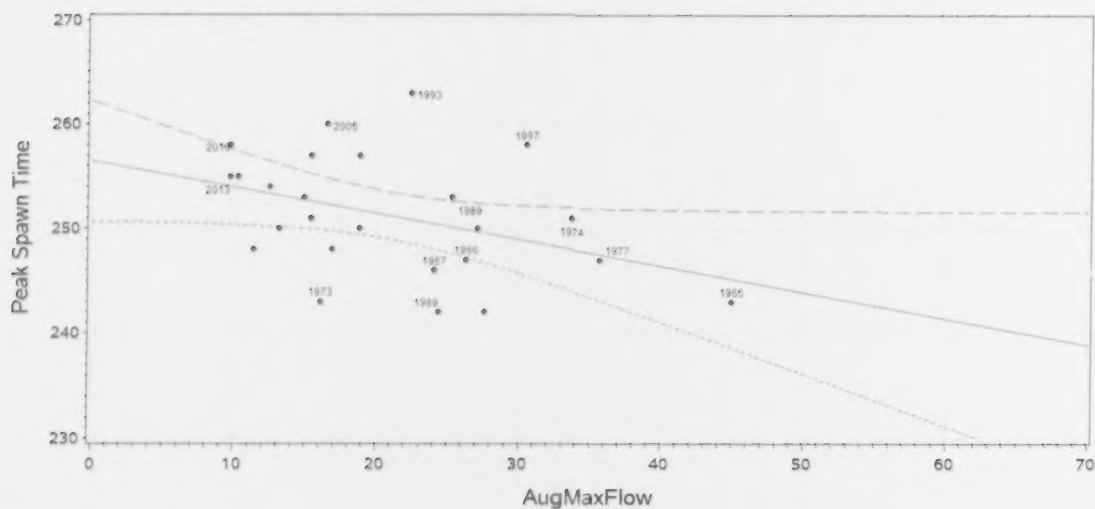


Figure 64. Annual date of peak spawn timing for adult Sockeye on the Horsefly spawning grounds as a function of Horsefly River maximum daily discharge in August ($r^2 = 0.35$; $P = 0.0037$, $n = 25$).

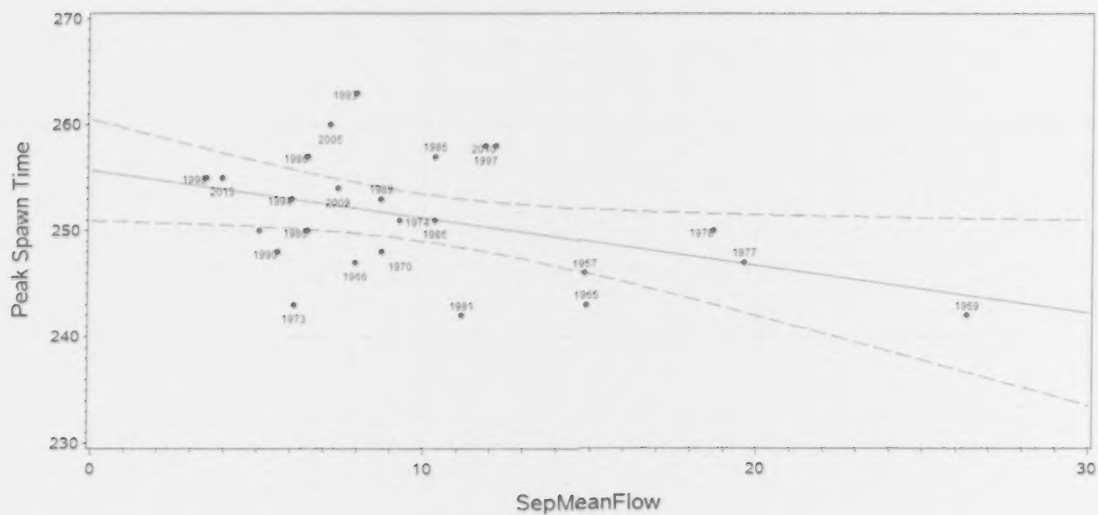


Figure 65. Annual date of peak spawn timing for adult Sockeye on the Horsefly spawning grounds as a function of Horsefly River mean daily discharge in September ($r^2 = 0.17$; $P = 0.038$, $n = 25$).

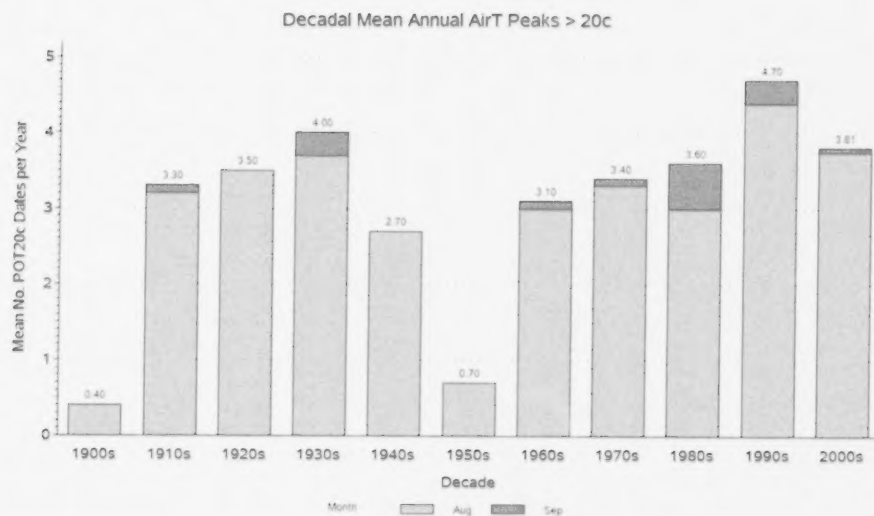


Figure 66. Frequency analysis of decadal mean number of dates per month in which regional daily mean air temperature (at ENV CANADA AHCCD station QUESNEL) exceeded 20°C (Aug-Sep). (Note: 2000s represents 2000-2015.)

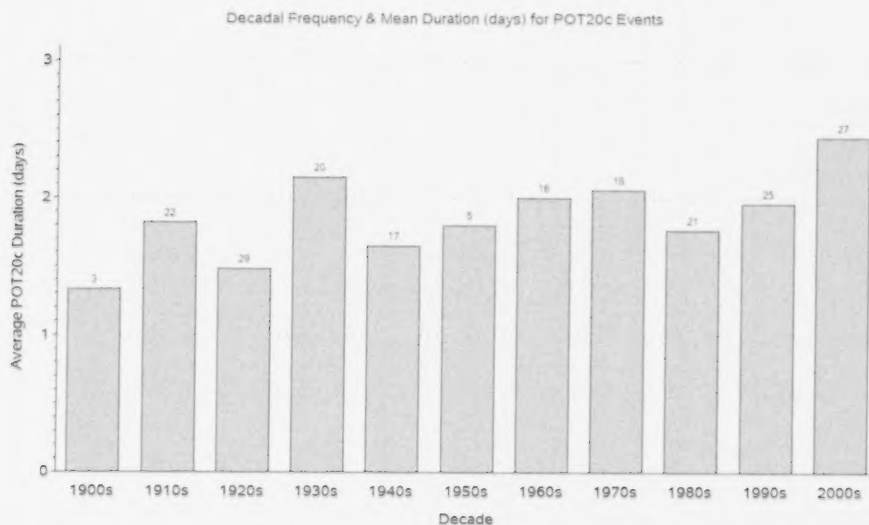


Figure 67. Mean length (days) and total decadal frequency of periods in which regional daily mean air temperature (at ENV CANADA AHCCD station QUESNEL) exceeded 20°C during Aug-Sep. (Note: 2000s represents 2000-2015.)

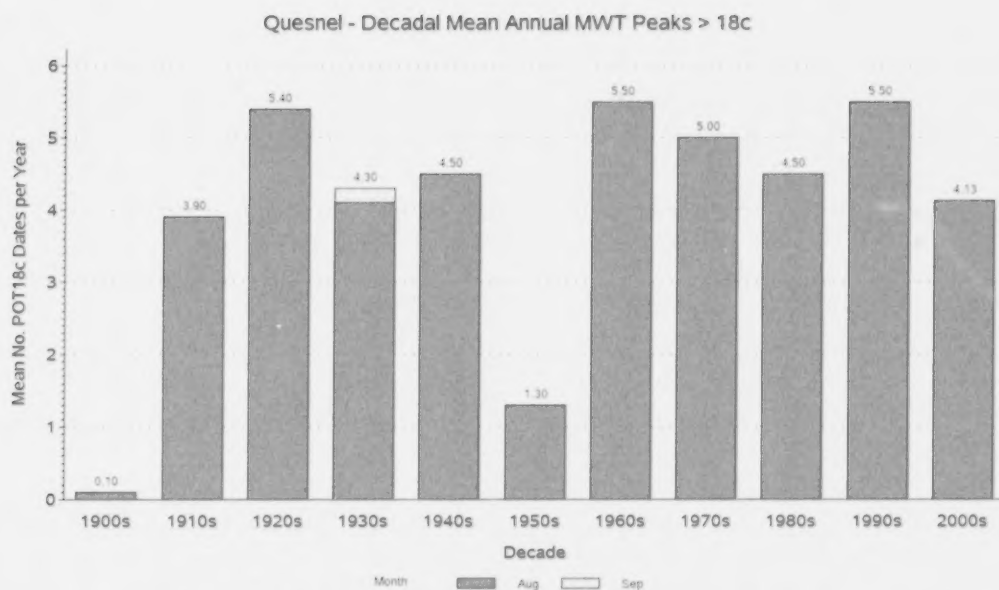


Figure 68. Frequency analysis of decadal mean number of dates per month (Aug-Sep) in which estimated mean water temperature in the lower Quesnel River exceeded 18°C. (Note: 2000s represents 2000-2015.)

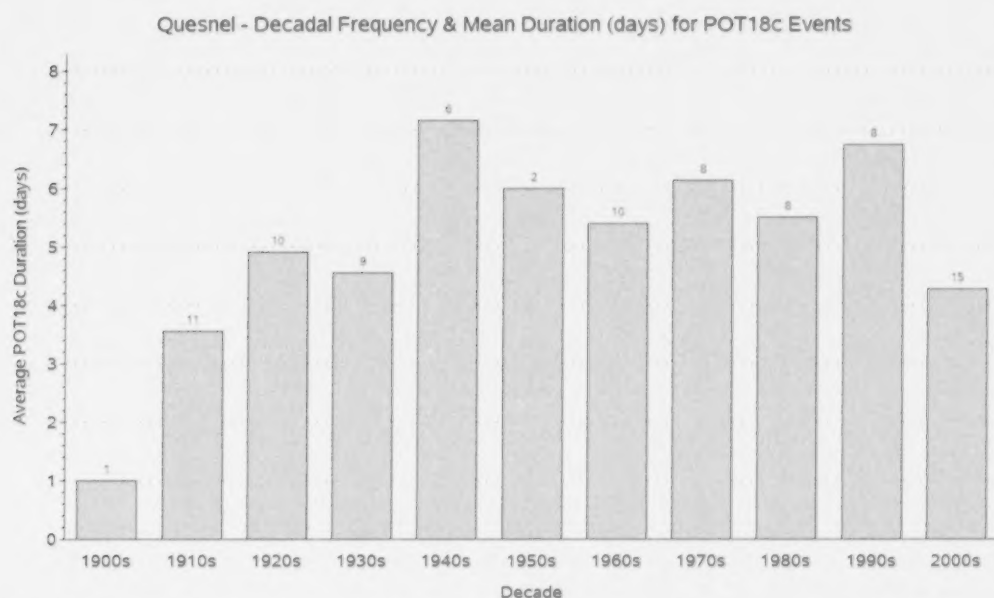


Figure 69. Mean length (days) and total decadal frequency of periods in which estimated daily mean water temperature (Aug-Sep) in the lower Quesnel River continuously exceeded 18°C, by decade. (Note: 2000s represents 2000-2015.)

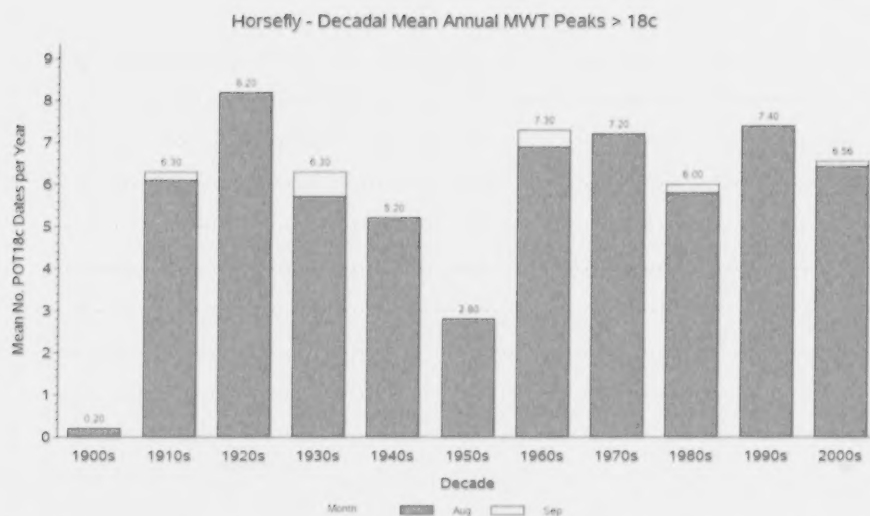


Figure 70. Frequency analysis of decadal mean number of dates per month (Aug-Sep) in which estimated mean water temperature in the lower Horsefly River exceeded 18°C. (Note: 2000s represents 2000-2015.)

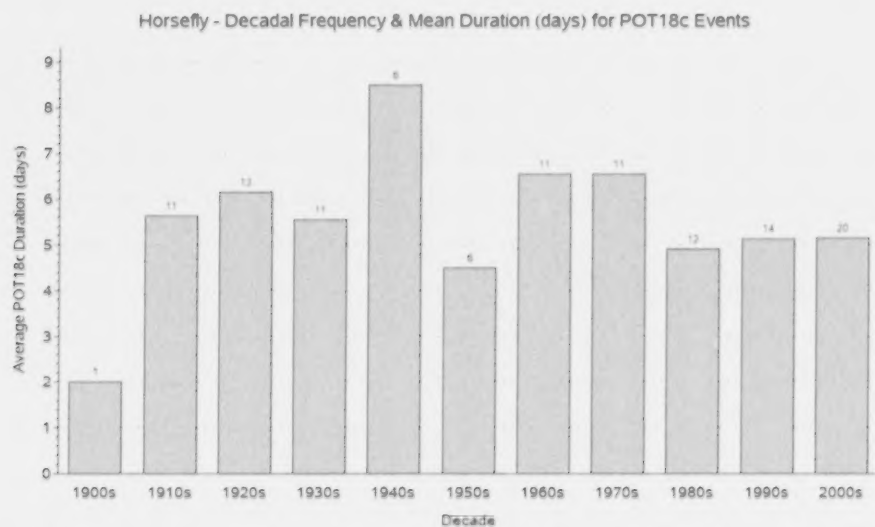


Figure 71. Mean length (days) and total decadal frequency of periods in which estimated daily mean water temperature (Aug-Sep) in the lower Horsefly River continuously exceeded 18°C, by decade. (Note: 2000s represents 2000-2015.)

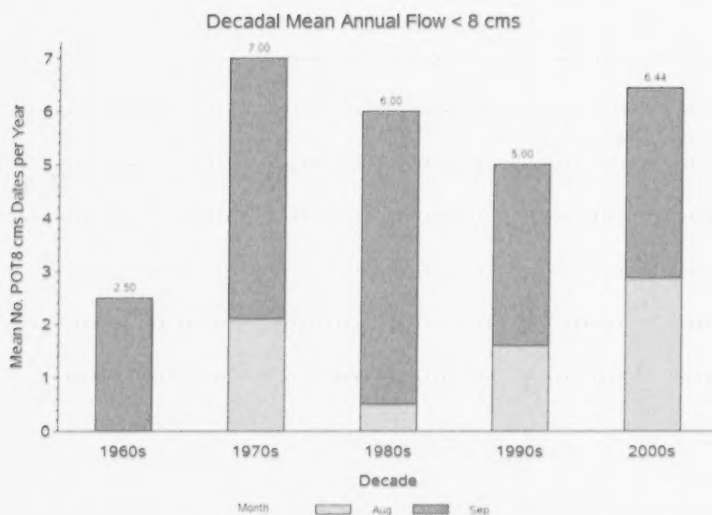


Figure 72. Frequency analysis of decadal mean number of "low flow" dates (< 8 cms, 10th percentile) per month in the lower Horsefly River. (Note: 1960s represents only 1965-1969; 2000s represents 2000-2015).

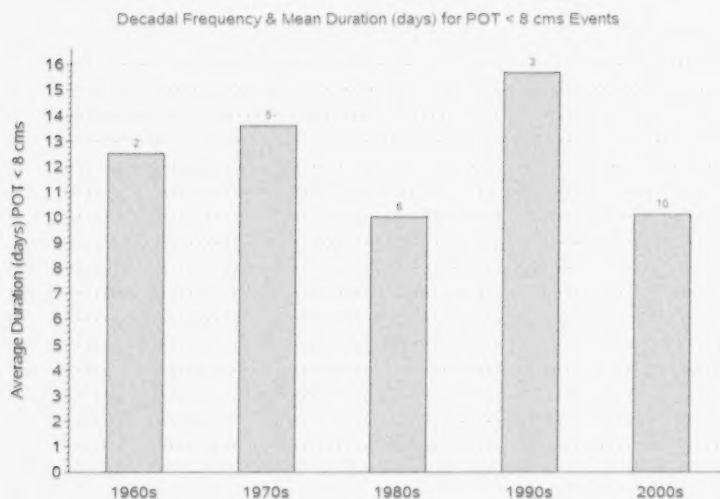


Figure 73. Mean length (days) and frequency of "low flow" periods in which lower HORSEFLY discharge continuously remained below the 10th percentile of August-September flows (~8 cms) (Note: 1960s represents only 1965-1969; 2000s represents 2000-2015).

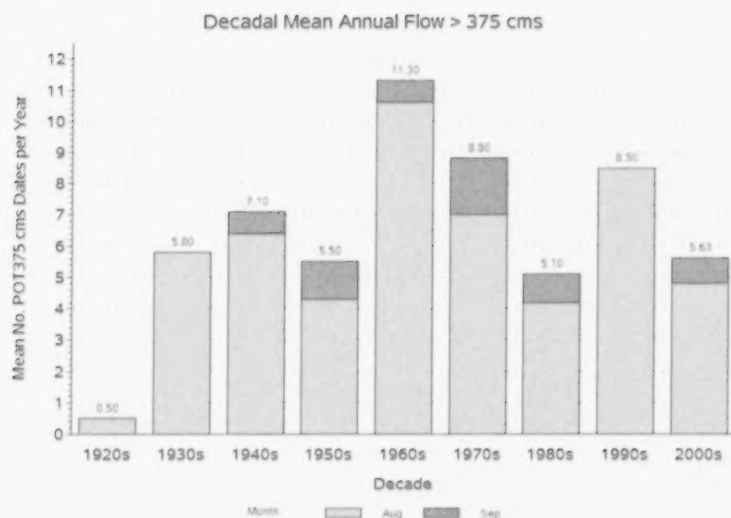


Figure 74. Frequency analysis of decadal mean number of "high flow" dates (i.e. >75th percentile of August-September flows: ~375 cms) per month in the lower Quesnel River (Note: 2000s represents 2000-2015).

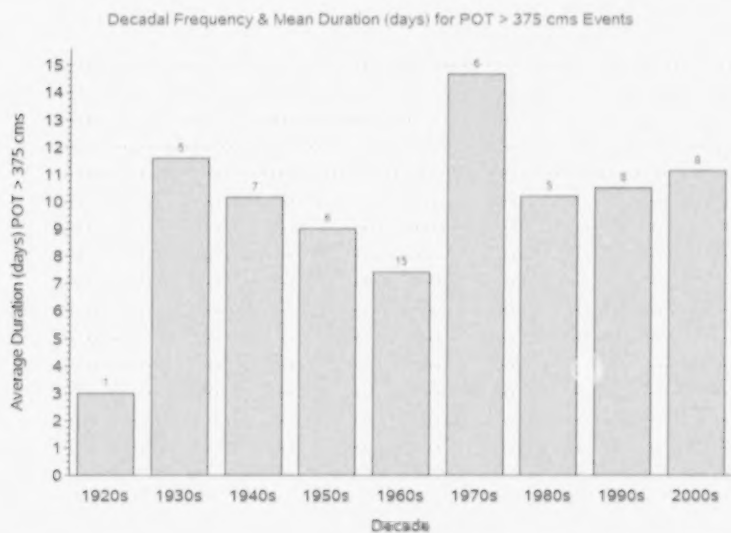


Figure 75. Mean length (days) and frequency of "high flow" periods in which lower Quesnel River discharge continuously remained above the 75th percentile of August-September flows (~375 cms) (Note: 2000s represents 2000-2015).

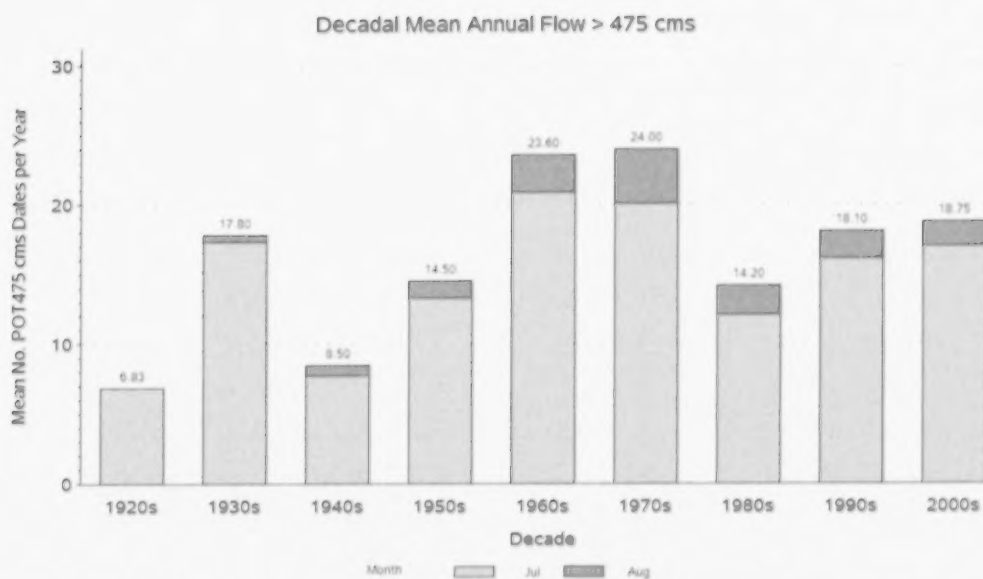


Figure 76. Frequency analysis of decadal mean number of early summer "200-year flood" dates (i.e. >99th percentile of July-August flows: ~475 cms) per month in the lower Quesnel River (Note: 2000s represents 2000-2015).

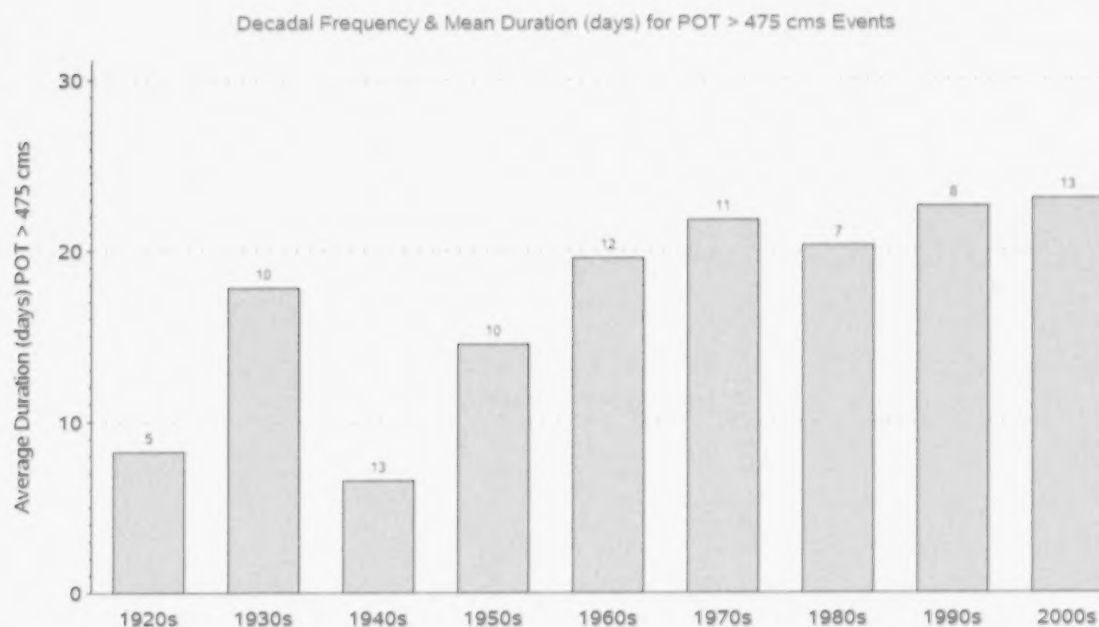


Figure 77. Mean length (days) and frequency of early summer "flood" periods in which lower Quesnel River discharge continuously remained above the 99th percentile of July-August flows (~475 cms) (Note: 2000s = 2000-2015).

APPENDICES

Appendix A. QUESNEL-S Sockeye Salmon conservation unit (CU) enumeration sites that occur in the escapement database. A checkmark beside the site name indicates its use in the escapement time series to evaluate CU status for *Trends in Abundance* metrics (from: Appendix 1 in Grant et al. 2011).

Quesnel-S

Sites	IN	Sites	IN	Sites	IN
Abbott Creek		Isaiah Creek		Tisdall Creek	
Amos Creek		Junction Creek		Trickle Creek	
Archie Creek		Junction Creek - shore		Wasko Creek	
Baxter Beach		Killdog Creek		Wasko Creek - shore	
Bear Beach - shore		Killdog Creek - shore		Watt Creek	
Betty Frank's - shore		Lester Shore		Watt Creek - shore	
Big Slide - shore		Limestone Creek		Whiffle Creek	
Big Slide - shore 1km West		Limestone Point - shore		Winkley Creek	
Bill Miner Creek		Limestone Point - shore 5km South			
Bill Miner Creek - shore		Little Horsefly River	✓		
Bill Miner Creek - shore 3km West		Logger Landing			
Blue Lead Creek		Long Creek			
Blue Lead Creek - shore		Long Creek - shore			
Bouldery Creek		Lynx Creek			
Bouldery Creek - shore		Lynx Creek - shore			
Bouldery Creek - shore 2km East		Marten Creek			
Bowling Point		Marten Creek - shore			
Buckingham Creek		McKinley Creek	✓		
Cameron Creek	✓	McKinley Creek - Lower	✓		
Clearbrook Creek		McKinley Creek - Upper	✓		
Deception Point		Mitchell River	✓		
Devos Creek		Moffat Creek			
Devos Creek - shore		Niagara Creek			
Double T - shore		North Arm - shore (Bowling-Goose Pt.)			
East Arm - shore (Rock Slide-Penninsula Pt.)		North Arm - shore (Roaring-Deception Pt.)			
East Arm - unnamed creek 1		North Arm - unnamed cove			
East Arm - unnamed creek 2 - shore		Opa Beach			
East Arm - unnamed point		Penfold Camp Shore			
Elysia - shore		Penfold Creek	✓		
Elysia - shore 1km West		Quartz Point			
Franks Creek		Quesnel Lake			
Franks Creek - shore		Raft Creek			
Goose Creek		Roaring Point			
Goose Point - shore		Roaring River			
Goose Point - shore 8km South		Roaring River - shore			
Grain Creek		Rock Slide			
Grain Creek - shore		Service Creek			
Hazeltine Creek		Slate Bay			
Horsefly Channel	✓	Slate Bay 1km East			
Horsefly Lake		Spusks Creek			
Horsefly River	✓	Sue Creek			
Horsefly River - Above Falls	✓	Summit Creek			
Horsefly River - Lower	✓	Taku Creek			
Horsefly River - Upper	✓	Tasse Creek			
Hurricane Point		Tasse Creek - shore			

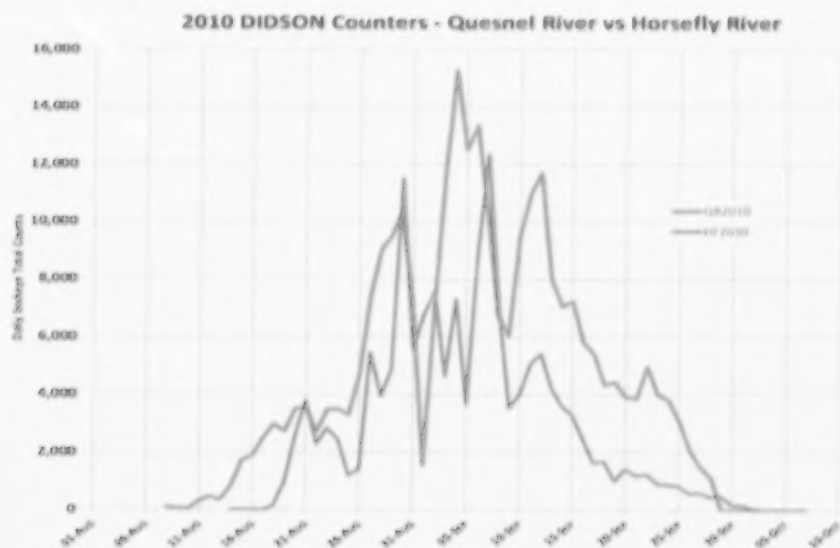
Appendix B. Daily totals of visual counts of adult Sockeye for 15-minute counting efforts at Likely Bridge, Quesnel River, by year and date, 1993-2001.

Date	1993			1994			1995			1997			1998			1999			2001			Multi-Year Avg %	
	Counts	Fish	Percent	Counts	Fish	Percent	Counts	Fish	Percent	Counts	Fish	Percent	Counts	Fish	Percent	Counts	Fish	Percent	Counts	Fish	Percent		
01-Aug			0.0%			0.0%			0.0%	8	0	0.0%	8	0	0.0%				8	0	0.0%	0.0%	
02-Aug			0.0%			0.0%			0.0%			0.0%	8	0	0.0%				8	0	0.0%	0.0%	
03-Aug			0.0%			0.0%			0.0%	8	0	0.0%	8	0	0.0%				8	0	0.0%	0.0%	
04-Aug			0.0%			0.0%			0.0%			0.0%	8	0	0.0%				8	0	0.0%	0.0%	
05-Aug			0.0%			0.0%			0.0%	8	0	0.0%	8	26	0.1%				8	2	0.0%	0.0%	
06-Aug			0.0%			0.0%			0.0%	8	0	0.0%	8	42	0.1%				8	7	0.0%	0.0%	
07-Aug			0.0%			0.0%			0.0%	8	0	0.0%	8	45	0.1%				8	1	0.0%	0.0%	
08-Aug			0.0%			0.0%			0.0%	8	2	0.0%	8	27	0.1%				8	3	0.0%	0.0%	
09-Aug			0.0%			0.0%			0.0%	8	3	0.0%	8	61	0.1%				8	1	0.0%	0.0%	
10-Aug			0.0%			0.0%			0.0%	8	0	0.0%	8	34	0.1%				8	1	0.0%	0.0%	
11-Aug			0.0%			0.0%			0.0%	8	3	0.0%	8	26	0.1%				8	5	0.0%	0.0%	
12-Aug			0.0%			0.0%			0.0%	8	1,173	0.5%	8	49	0.1%	8	0		8	25	0.0%	0.1%	
13-Aug	4	7	0.0%			0.0%			0.0%	8	1,910	0.8%	8	37	0.1%	8	5		8	259	0.1%	0.2%	
14-Aug	4	1	0.0%			0.0%			0.0%	8	1,323	0.6%	8	116	0.3%	8	2		8	763	0.3%	0.2%	
15-Aug	4	6	0.0%	4	118	0.4%			0.0%	8	869	0.4%	8	102	0.2%	8	9		8	760	0.3%	0.2%	
16-Aug	4	8	0.0%	4	328	1.2%			0.0%	8	150	0.1%	8	523	1.2%	8	12		8	729	0.3%	0.5%	
17-Aug	4	6	0.0%	4	1,152	4.2%			0.0%	8	2,079	0.9%	8	1,234	2.7%	8	56		8	898	0.4%	1.4%	
18-Aug	4	7	0.0%	4	937	3.4%			0.0%	8	1,629	0.7%	8	859	1.9%	8	43		8	872	0.4%	1.1%	
19-Aug	4	44	0.0%	4	1,153	4.2%			0.0%	8	1,386	0.6%	8	674	1.5%	8	68		8	4,222	1.7%	1.3%	
20-Aug	4	191	0.2%	4	1,917	6.0%			0.0%	8	756	0.3%	8	412	0.9%	8	18		8	3,400	1.4%	1.5%	
21-Aug	4	332	0.4%	4	1,509	5.4%	6	589	4.8%	8	481	0.2%	8	304	0.7%	8	327		8	4,550	1.8%	2.2%	
22-Aug	4	653	0.7%	4	798	2.9%	6	957	7.7%	8	788	0.3%	8	853	1.9%	8	321		8	4,910	2.0%	2.6%	
23-Aug	4	1,142	1.2%	4	207	0.7%	7	986	8.0%	8	1,081	0.5%	8	1,211	2.7%				8	2,434	1.0%	2.4%	
24-Aug	4	421	0.5%	4	113	0.4%	8	1,648	13.3%	4	1,094	0.4%	8	3,188	7.1%				8	2,171	0.9%	3.8%	
25-Aug	4	402	0.4%	4	168	0.6%	8	648	5.2%	8	1,749	0.8%	8	4,308	9.8%				8	3,455	1.4%	3.0%	
26-Aug	4	622	0.7%	4	689	2.5%	8	358	2.9%	8	971	0.4%	8	2,973	6.8%				8	1,264	0.5%	2.3%	
27-Aug	4	1,081	1.2%	4	1,131	4.1%	8	923	7.4%	8	725	0.3%	8	2,010	4.6%				8	4,287	1.7%	3.2%	
28-Aug	4	1,220	1.3%	4	1,724	6.2%	8	1,705	13.7%	8	1,640	0.7%	8	979	2.2%				8	5,219	2.1%	4.8%	
29-Aug	4	450	0.5%	4	1,652	6.0%	8	1,232	9.8%	8	3,989	1.6%	8	1,181	2.6%				8	5,321	2.1%	3.8%	
30-Aug	4	520	0.6%	4	1,734	6.3%	8	836	6.7%	7	4,301	1.8%	8	1,474	3.3%				8	4,576	1.8%	3.4%	
31-Aug	4	311	0.3%	4	1,689	6.1%	8	945	7.8%	8	5,003	2.2%	8	2,103	4.7%				8	6,165	2.5%	3.9%	
01-Sep	4	226	0.2%	4	1,230	4.4%	8	1,040	8.4%	7	3,459	1.5%	8	1,910	4.2%				8	9,038	3.6%	3.7%	
02-Sep	4	701	0.8%	6	825	3.0%	8	156	1.2%	8	2,627	1.1%	8	1,166	2.6%				8	12,695	5.1%	2.3%	
03-Sep	4	450	0.5%	6	402	1.4%	8	19	0.2%	8	3,943	1.7%	8	1,092	2.4%				8	15,566	6.2%	2.1%	
04-Sep	4	724	0.8%	6	737	2.7%	8	29	0.2%	8	7,782	3.4%	8	1,263	2.9%				8	16,794	6.7%	2.8%	
05-Sep	4	1,306	1.4%	6	957	3.6%	8	15	0.1%	8	12,120	5.3%	8	1,795	4.0%				8	10,648	4.3%	3.1%	
06-Sep	4	2,039	2.2%	6	449	1.6%	8	82	0.7%	8	19,133	8.3%	8	2,475	5.6%				8	10,380	4.2%	3.8%	
07-Sep	4	3,469	3.8%	6	202	0.7%	8	69	0.6%	8	17,818	7.7%	8	1,946	3.7%				8	14,671	5.9%	3.7%	
08-Sep	4	3,402	3.7%	6	439	1.6%	8	7	0.1%	8	21,277	9.2%	8	1,840	4.1%				8	12,682	5.1%	4.0%	
09-Sep	4	5,932	6.4%	6	667	2.5%	8	4	0.0%	8	23,884	10.4%	8	1,611	3.6%				8	11,890	4.8%	4.6%	
10-Sep	4	7,333	7.9%	6	576	2.1%	8	4	0.0%	8	20,626	9.0%	8	1,369	3.0%				8	9,201	3.7%	4.3%	
11-Sep	4	9,479	10.2%	6	1,132	4.1%	8	5	0.0%	8	13,795	6.0%	8	870	1.9%				8	8,977	3.6%	4.3%	
12-Sep	4	7,007	7.6%	6	1,022	3.7%	8	13	0.1%	8	8,954	3.9%	8	596	1.3%				8	5,549	2.2%	3.1%	
13-Sep	4	8,632	9.3%	6	464	1.7%	8	18	0.1%	8	6,977	3.0%	8	594	1.3%				8	5,931	2.4%	3.0%	
14-Sep	4	9,265	10.0%	6	146	0.5%	8	36	0.3%	8	5,649	2.5%	8	339	0.8%				8	6,617	2.7%	2.8%	
15-Sep	4	5,740	6.2%	6	172	0.6%	8	23	0.2%	8	1,746	0.8%	8	457	1.0%				8	6,586	2.6%	1.9%	
16-Sep	4	3,889	4.2%	6	144	0.5%	8	23	0.2%	8	1,238	0.5%	8	268	0.6%				8	3,898	1.6%	1.3%	
17-Sep	4	2,688	2.9%	6	117	0.4%	8	22	0.2%	8	920	0.4%	8	140	0.3%				8	3,544	1.4%	0.9%	
18-Sep	4	2,788	3.0%	6	340	1.2%	8	16	0.1%	8	1,068	0.5%	8	128	0.3%				8	3,167	1.3%	1.1%	
19-Sep	4	2,690	2.9%	6	233	0.8%			0.0%	8	1,107	0.5%	8	92	0.2%				8	3,104	1.2%	0.9%	
20-Sep	4	1,085	1.2%	6	179	0.6%			0.0%	8	891	0.3%	8	53	0.1%				8	4,704	1.9%	0.7%	
21-Sep	4	578	0.6%	6	102	0.4%			0.0%	8	1,612	0.7%	8	50	0.1%				8	2,774	1.1%	0.5%	
22-Sep	4	372	0.4%	6	102	0.4%			0.0%	8	2,019	0.9%	8	48	0.1%				8	2,482	1.0%	0.5%	
23-Sep	4	310	0.3%	6	81	0.3%			0.0%	8	2,104	0.9%	8	81	0.2%				8	2,457	1.0%	0.5%	
24-Sep	4	202	0.2%	6	62	0.2%			0.0%	6	1,215	0.5%	8	60	0.1%				8	2,233	0.9%	0.3%	
25-Sep	4	480	0.5%	6	42	0.2%			0.0%	8	1,462	0.6%	8	55	0.1%				8	2,311	0.9%	0.4%	
26-Sep	4	894	0.9%	3	8	0.0%			0.0%	8	1,497	0.7%	8	23	0.1%				8	1,282	0.5%	0.4%	
27-Sep	4	872	0.9%	6	14	0.1%			0.0%	8	1,342	0.6%	8	16	0.0%							0.0%	0.3%
28-Sep	4	898	0.9%	6	34	0.1%			0.0%	8	1,128	0.5%	8	7	0.0%				8	1,109	0.4%	0.3%	
29-Sep	4	498	0.5%	6	7	0.0%			0.0%	8	1,308	0.6%	8	10	0.0%				8	724	0.3%	0.2%	
30-Sep	4	456	0.5%	8	7	0.0%			0.0%	8	1,319	0.6%	8	6	0.0%				8	611	0.2%	0.2%	
01-Oct	4	287	0.3%	6	5	0.0%			0.0%	8	1,517	0.7%			0.0%				8	163	0.1%	0.2%	
02-Oct	4	253	0.3%			0.0%			0.0%	8	1,538	0.7%			0.0%				8	290	0.1%	0.2%	
03-Oct	4	250	0.3%			0.0%			0.0%	8	1,641	0.7%			0.0%				8	238	0.1%	0.2%	
04-Oct			0.0%			0.0%			0.0%	8	1,383	0.6%			0.0%				8	278	0.1%	0.1%	
05-Oct			0.0%			0.0%			0.0%	8	528	0.2%			0.0%				8	197	0.1%	0.1%	
06-Oct			0.0%			0.0%			0.0%	8	775	0.3%			0.0%				8	44	0.0%	0.1%	
07-Oct			0.0%			0.0%			0.0%	8	256	0.1%			0.0%							0.0%	0.0%
08-Oct			0.0%			0.0%			0.0%	8	221	0.1%			0.0%								

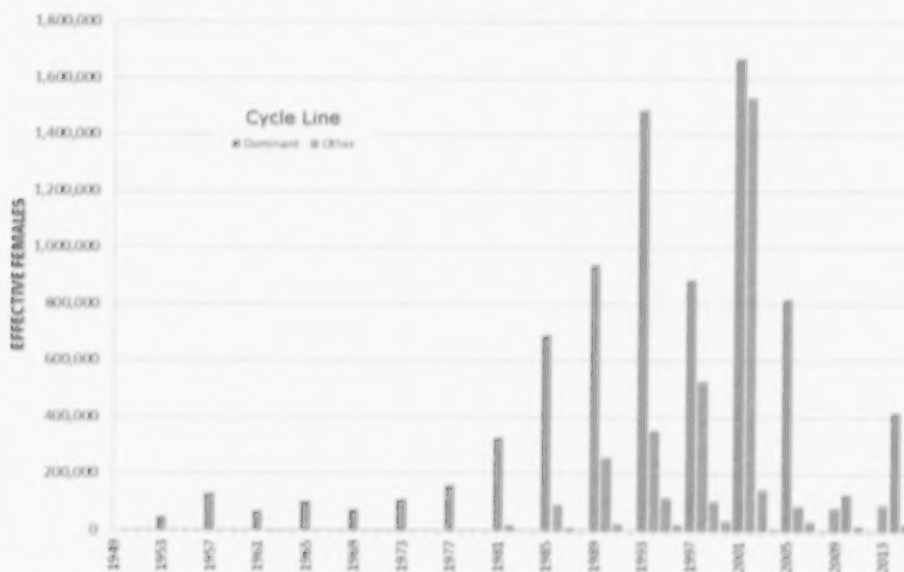
Appendix C. Daily totals of Sockeye Salmon enumerated via DIDSON acoustic imaging systems in Quesnel River (left), and Horsefly River (right).

Date	2009	2010	2014	2015	Date	2005	2006	2007	2010
01-Aug					01-Aug	-	-	-	-
02-Aug					02-Aug	-	-	-	-
03-Aug					03-Aug	-	-	-	-
04-Aug					04-Aug	-	-	-	-
05-Aug					05-Aug	-	-	-	-
06-Aug					06-Aug	14	-	-	-
07-Aug					07-Aug	38	-	-	-
08-Aug	6	114			08-Aug	42	-	-	-
09-Aug	11	63			09-Aug	16	6	-	-
10-Aug	64	39			10-Aug	26	39	-	-
11-Aug	131	306			11-Aug	6	21	-	-
12-Aug	173	459			12-Aug	16	15	-	-
13-Aug	215	360		66	13-Aug	84	9	24	-
14-Aug	392	858	18	180	14-Aug	48	15	24	14
15-Aug	534	1,710	108	243	15-Aug	60	24	15	12
16-Aug	414	1,911	782	281	16-Aug	42	24	5	12
17-Aug	1,772	2,507	4,799	280	17-Aug	39	15	17	11
18-Aug	2,744	2,963	8,255	315	18-Aug	420	27	11	134
19-Aug	3,122	2,732	7,903	194	19-Aug	849	117	54	966
20-Aug	5,124	3,516	6,877	303	20-Aug	321	182	75	2,561
21-Aug	4,955	3,524	5,243	662	21-Aug	894	382	144	3,801
22-Aug	4,271	2,712	6,602	486	22-Aug	1,116	1,047	564	2,297
23-Aug	5,837	3,491	6,020	1,025	23-Aug	1,956	1,705	2,348	2,828
24-Aug	7,307	3,488	4,514	701	24-Aug	1,020	3,098	1,539	2,456
25-Aug	5,676	3,302	6,666	662	25-Aug	3,254	2,063	4,511	1,229
26-Aug	2,825	4,721	13,777	596	26-Aug	2,426	1,581	6,878	1,427
27-Aug	3,840	7,454	16,545	720	27-Aug	5,219	1,937	3,857	5,435
28-Aug	3,909	9,054	17,510	1,259	28-Aug	2,695	1,904	4,377	3,957
29-Aug	5,837	9,480	24,278	1,191	29-Aug	3,591	2,820	2,514	4,854
30-Aug	8,262	10,353	31,185	1,245	30-Aug	4,804	4,428	2,760	11,507
31-Aug	7,476	7,107	34,219	1,264	31-Aug	3,370	5,645	1,189	5,576
01-Sep	5,244	1,572	31,749	1,212	01-Sep	4,047	4,466	2,823	6,755
02-Sep	4,769	6,756	30,915	1,287	02-Sep	4,922	3,114	5,159	7,581
03-Sep	4,127	11,610	30,587	1,200	03-Sep	3,783	2,604	2,708	4,635
04-Sep	5,748	15,278	31,296	1,331	04-Sep	4,301	2,078	2,379	7,291
05-Sep	6,393	12,506	35,324	1,373	05-Sep	10,264	2,336	876	3,658
06-Sep	5,933	13,349	31,977	1,547	06-Sep	9,812	2,294	516	8,753
07-Sep	4,769	10,301	21,354	1,875	07-Sep	8,854	2,554	836	12,333
08-Sep	4,419	6,743	19,069	1,575	08-Sep	16,835	2,815	1,836	7,106
09-Sep	3,702	6,048	16,643	1,764	09-Sep	19,823	3,819	2,143	3,546
10-Sep	3,411	9,477	14,808	1,613	10-Sep	35,789	1,376	950	4,022
11-Sep	2,726	10,970	14,063	1,980	11-Sep	41,207	3,691	826	5,076
12-Sep	2,786	11,693	26,681	1,800	12-Sep	31,533	2,479	1,042	5,409
13-Sep	2,303	7,983	31,675	1,472	13-Sep	66,488	4,183	1,583	4,194
14-Sep	2,037	7,067	42,740	1,330	14-Sep	53,157	3,438	807	3,603
15-Sep	2,164	7,220	45,066	864	15-Sep	30,462	3,676	1,169	3,291
16-Sep	2,432	5,807	36,870	1,095	16-Sep	30,570	2,882	1,009	2,472
17-Sep	2,802	5,411	17,589	1,080	17-Sep	33,736	2,042	673	1,647
18-Sep	3,512	4,349	22,955	768	18-Sep	27,819	2,704	683	1,691
19-Sep	2,303	4,436	30,113	626	19-Sep	27,766	1,225	374	1,023
20-Sep	2,460	3,917	34,904	908	20-Sep	16,741	1,471	170	1,410
21-Sep	1,697	3,876	28,721	669	21-Sep	16,947	1,029	386	1,206
22-Sep	1,496	4,971	16,082	455	22-Sep	16,816	599	301	1,238
23-Sep	1,140	4,011	7,338	672	23-Sep	13,518	490	159	924
24-Sep	828	3,800	4,527	650	24-Sep	13,111	850	37	886
25-Sep	738	3,084	2,300	548	25-Sep	12,572	460	116	837
26-Sep	576	2,069	1,869	647	26-Sep	14,284	225	-	581
27-Sep	431	1,490	1,199	531	27-Sep	13,397	309	-	591
28-Sep	424	1,124	810	462	28-Sep	11,691	215	-	608
29-Sep	345	-	754	159	29-Sep	8,604	273	-	671
30-Sep	285	-	538	0	30-Sep	5,860	149	-	291
01-Oct	230	-	384	0	01-Oct	3,237	2	-	155
02-Oct	170	-	274	0	02-Oct	1,909	-	-	46
03-Oct	120	-	195	0	03-Oct	2,012	-	-	0
04-Oct	80	-	139	0	04-Oct	1,050	-	-	-
05-Oct	45	-	0	0	05-Oct	969	-	-	-
06-Oct	10	-	0	0	06-Oct	704	-	-	-
07-Oct	-	-	0	0	07-Oct	224	-	-	-
08-Oct	-	-	0	0	08-Oct	78	-	-	-
09-Oct	-	-	0	0	09-Oct	57	-	-	-
10-Oct	-	-	0	0	10-Oct	-	-	-	-

Appendix D. Comparison of daily Sockeye counts in the upper Quesnel (QR) and lower Horsefly (HF) in 2010. First non-zero counts at QR occurred on August 8th and at HF on August 14th.



Appendix E. Annual Quesnel Sockeye escapement index (Effective Females) by return year (Source: Grant et al. 2011, Appendix 1 and 2, p. 71)⁶⁴.



⁶⁴ It is believed that the 2002 escapement abundance rivalled the 2001 dominant year, but since the 2002 escapement was unassessed by DFO personnel, there is only anecdotal evidence. Subsequent assessment data indicate that the 2002 cycle line became the dominant line by 2010 (Appendix E).

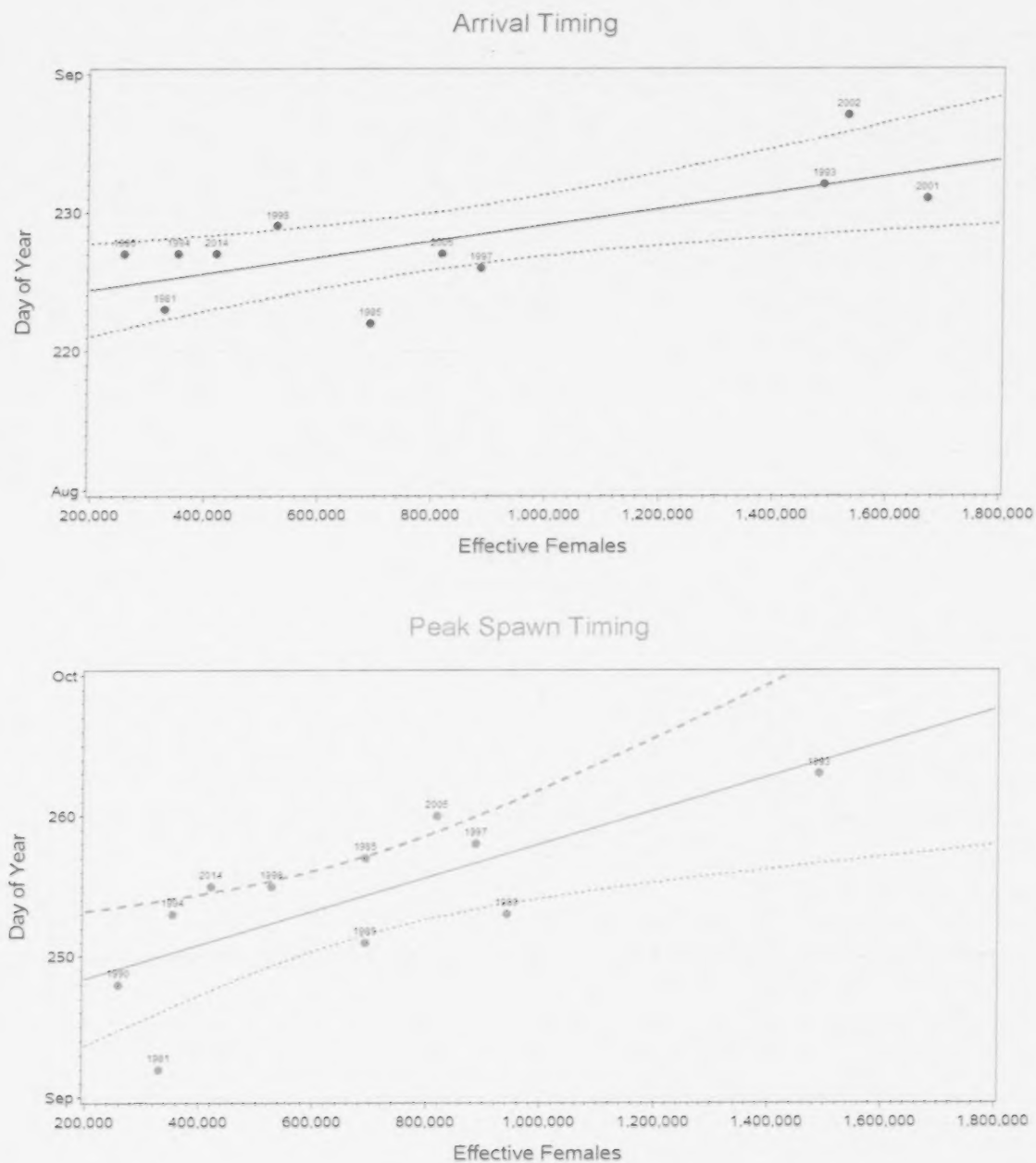
Appendix F. Quesnel/Horsefly annual Sockeye arrival timing (initial date and corresponding Julian day-of-year) and median date of peak spawn timing in Horsefly River, 1940-2015 (Source: Houtman and Cone 2000).

	Spawner Arrival	Arrival Time	Peak Spawn Timing	Peak Spawn Time
Year				
1940	01SEP1940	245	11SEP1940	255
1941	15AUG1941	227	27AUG1941	239
1942				
1943				
1944				
1945	14AUG1945	226	07SEP1945	250
1946	15AUG1946	227	30AUG1946	242
1947				
1948				
1949	08AUG1949	220	03SEP1949	246
1950	23AUG1950	235	26AUG1950	238
1951	20AUG1951	232	26AUG1951	238
1952	12AUG1952	225	30AUG1952	243
1953	04AUG1953	216	28AUG1953	240
1954	23AUG1954	235	03SEP1954	246
1955	21AUG1955	233	05SEP1955	248
1956	18AUG1956	231	31AUG1956	244
1957	05AUG1957	217	03SEP1957	246
1958	15AUG1958	227	08SEP1958	251
1959				
1960	19AUG1960	232	11SEP1960	255
1961	05AUG1961	217	29AUG1961	241
1962	23AUG1962	235	01SEP1962	244
1963	12AUG1963	224	27AUG1963	239
1964	25AUG1964	238	11SEP1964	255
1965	06AUG1965	218	31AUG1965	243
1966	15AUG1966	227	04SEP1966	247
1967	14AUG1967	226	03SEP1967	246
1968	20AUG1968	233	05SEP1968	249
1969	07AUG1969	219	30AUG1969	242
1970	24AUG1970	236	05SEP1970	248
1971			31AUG1971	243
1972	20AUG1972	233	07SEP1972	251
1973	14AUG1973	226	31AUG1973	243
1974			08SEP1974	251
1975			08SEP1975	251
1976	07SEP1976	251	17SEP1976	261
1977	09AUG1977	221	04SEP1977	247
1978	20AUG1978	232	07SEP1978	250
1979			13SEP1979	256
1980			10SEP1980	254
1981	11AUG1981	223	30AUG1981	242

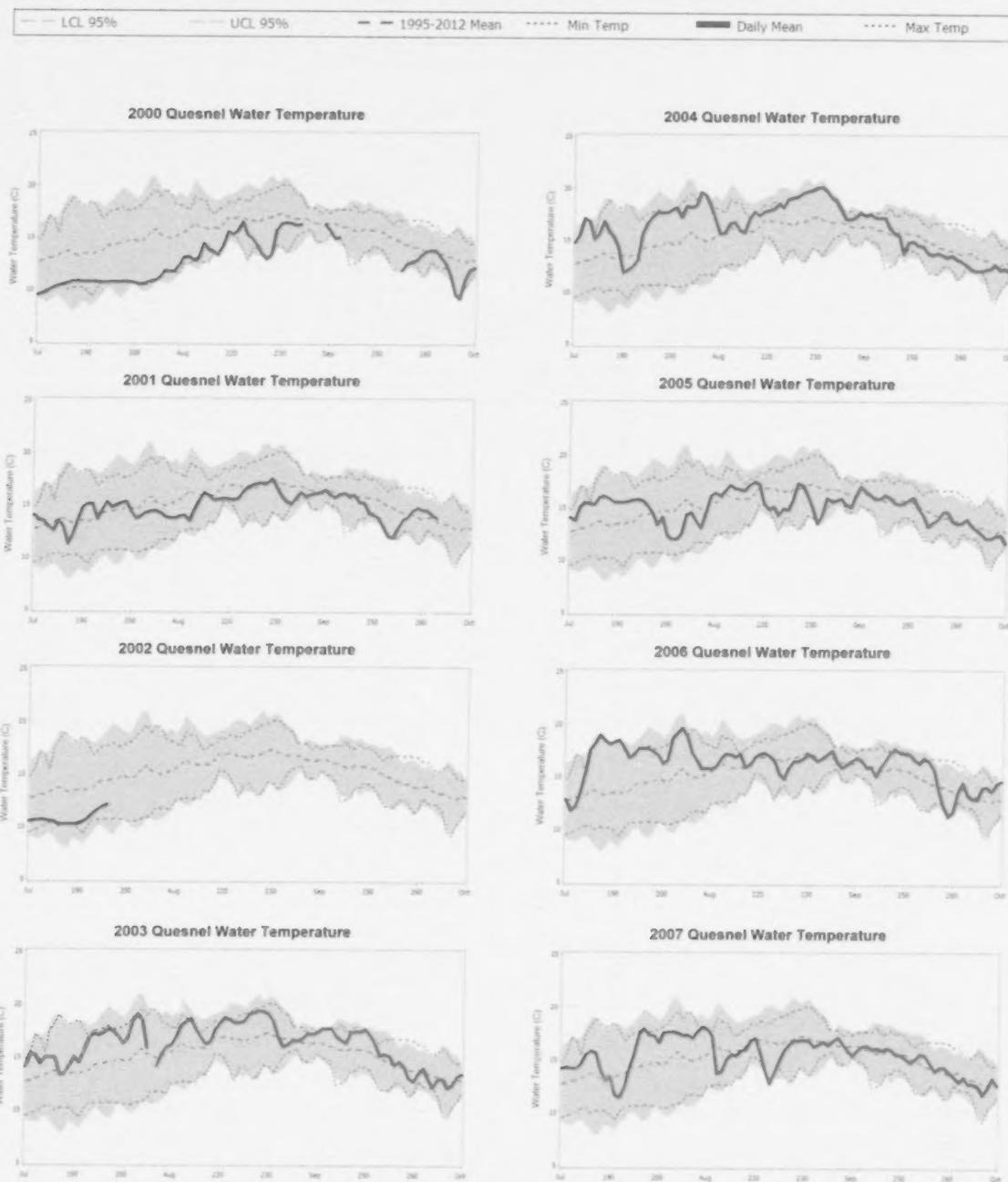
	Arrival (JulDate)						Peak Spawn (JulDate)					
	N	Rin	P10	Med	P90	Max	N	Rin	P10	Med	P90	Max
1940-2015	50	216	220	227	237	251	70	238	242	250	258	263

	Spawner Arrival	Arrival Time	Peak Spawn Timing	Peak Spawn Time
Year				
1982				
1983			06SEP1983	249
1984			06SEP1984	250
1985	10AUG1985	222	11SEP1985	254
1986			10SEP1986	254
1987			10SEP1987	254
1988	11AUG1988	224	08SEP1988	252
1989			10SEP1989	253
1990	15AUG1990	227	05SEP1990	248
1991				
1992				
1993	20AUG1993	232	20SEP1993	263
1994	15AUG1994	227	10SEP1994	253
1995	15AUG1995	227	09SEP1995	252
1996				
1997	14AUG1997	226	15SEP1997	258
1998	17AUG1998	229	12SEP1998	255
1999			05SEP1999	248
2000			05SEP2000	249
2001	19AUG2001	231		
2002	25AUG2002	237		
2003	25AUG2003	237	10SEP2003	253
2004			09SEP2004	253
2005	15AUG2005	227	17SEP2005	260
2006	21AUG2006	233	07SEP2006	250
2007	25AUG2007	237	10SEP2007	253
2008			07SEP2008	251
2009	15AUG2009	227	11SEP2009	254
2010	14AUG2010	226	15SEP2010	258
2011	25AUG2011	237	11SEP2011	254
2012			10SEP2012	254
2013	25AUG2013	237	12SEP2013	255
2014	15AUG2014	227	12SEP2014	255
2015			14SEP2015	257

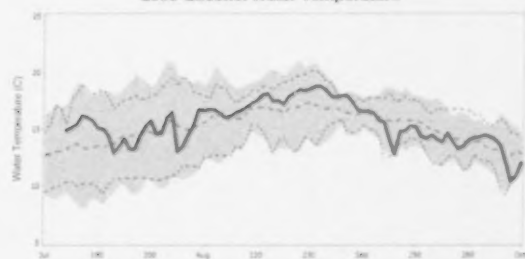
Appendix G. QUESNEL/HORSEFLY annual Sockeye arrival timing (initial date and corresponding Julian day-of-year) and median date of peak spawn timing in Horsefly River (Houtman and Cone 2000) for dominant and subdominant cycle years only, as a function of effective female spawners (Source: Grant et al. 2011, Appendix 1 and 2, p. 71). Restricted to years where Effective Females < 200,000 fish.



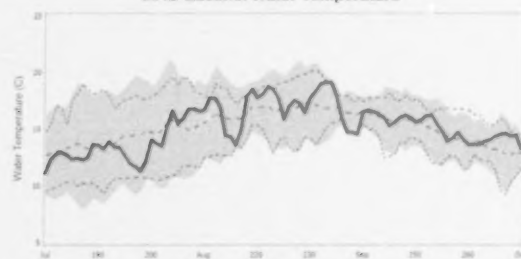
Appendix H. QUESNEL RIVER daily mean water temperature observations, by year, 2000-2015
 (Source: DFO ENVIRONMENTAL WATCH PROGRAM site QR-1, 2000-2012; ECCC
 WATER SURVEY OF CANADA station 08KH006, 2013-2015).



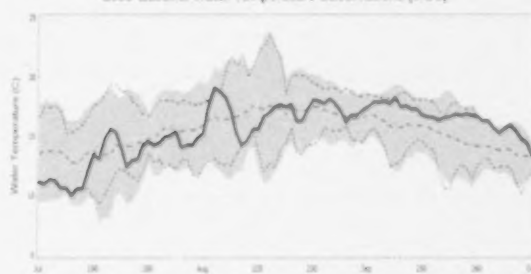
2008 Quesnel Water Temperature



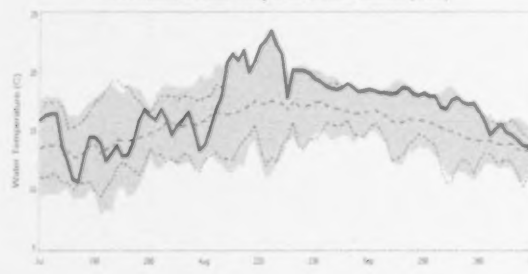
2012 Quesnel Water Temperature



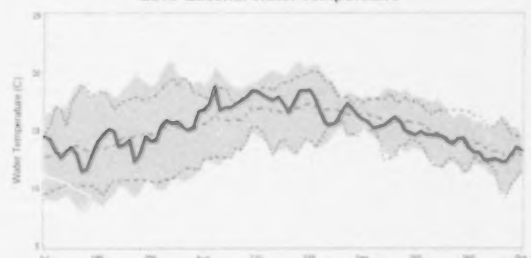
2009 Quesnel Water Temperature Observations (WSC)



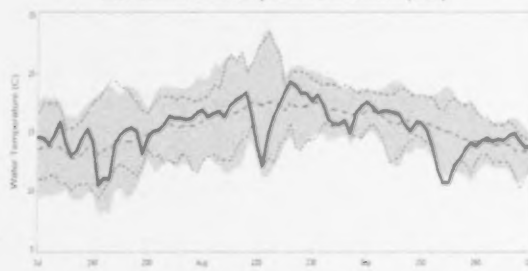
2013 Quesnel Water Temperature Observations (WSC)



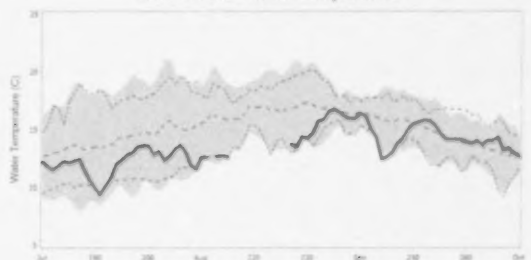
2010 Quesnel Water Temperature



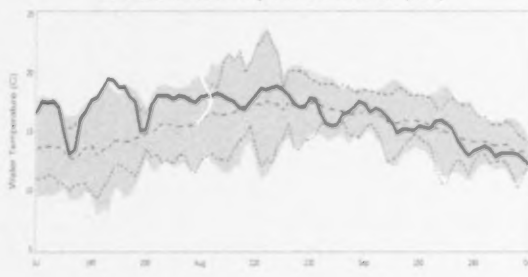
2014 Quesnel Water Temperature Observations (WSC)



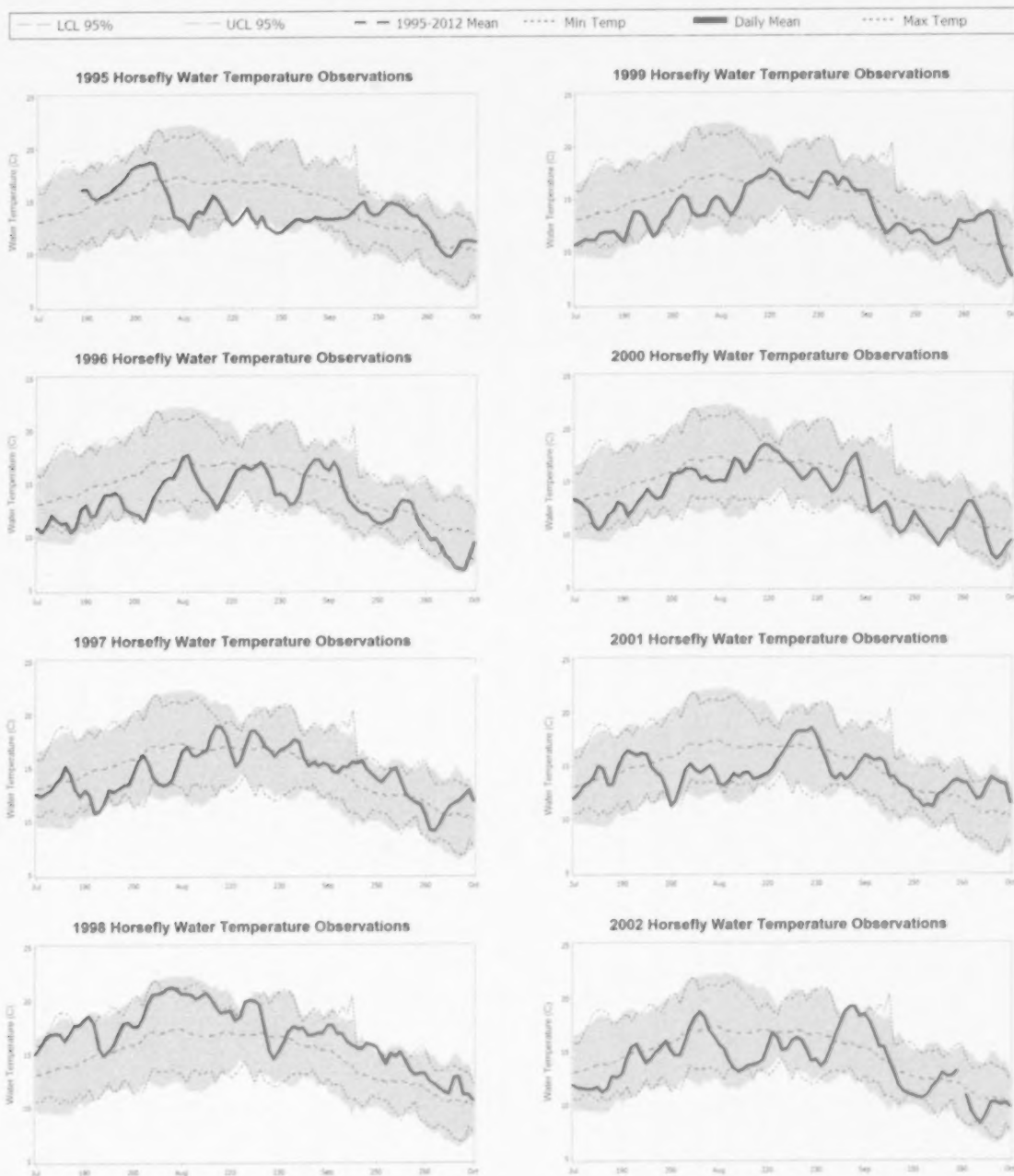
2011 Quesnel Water Temperature



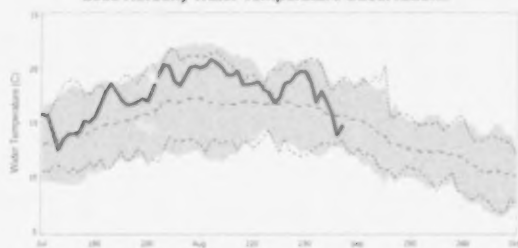
2015 Quesnel Water Temperature Observations (WSC)



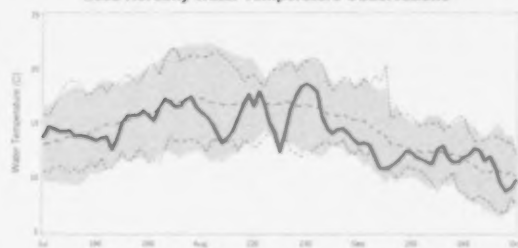
Appendix I. HORSEFLY RIVER daily mean water temperature observations, by year, 1995-2012
(Source: Site ID HR-22; DFO ENVIRONMENTAL WATCH PROGRAM).



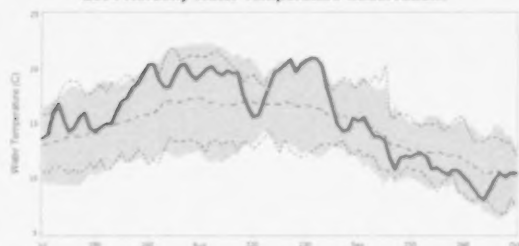
2003 Horsefly Water Temperature Observations



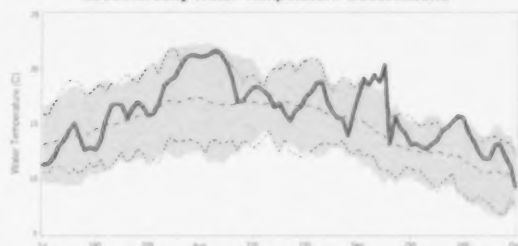
2008 Horsefly Water Temperature Observations



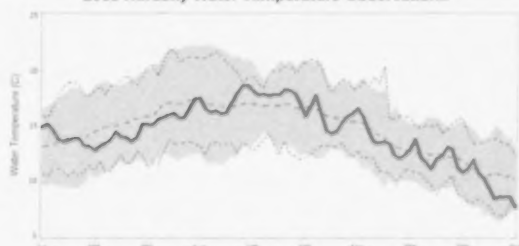
2004 Horsefly Water Temperature Observations



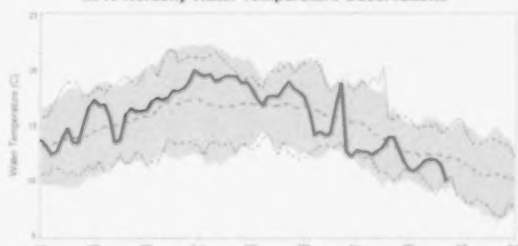
2009 Horsefly Water Temperature Observations



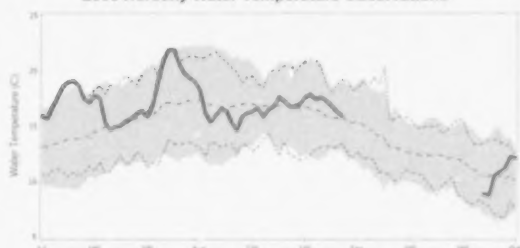
2005 Horsefly Water Temperature Observations



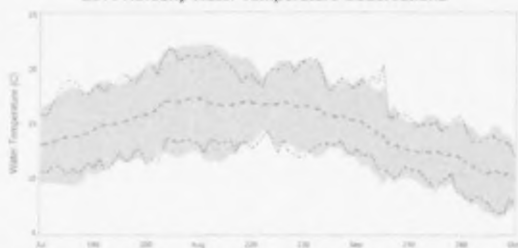
2010 Horsefly Water Temperature Observations



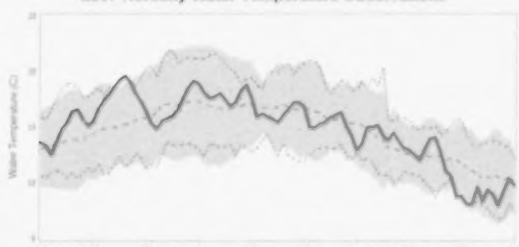
2006 Horsefly Water Temperature Observations



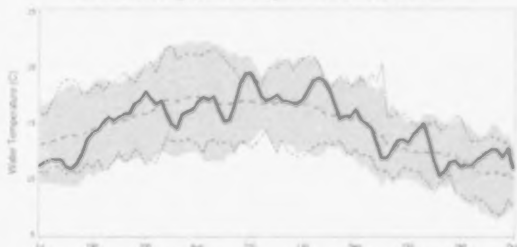
2011 Horsefly Water Temperature Observations



2007 Horsefly Water Temperature Observations



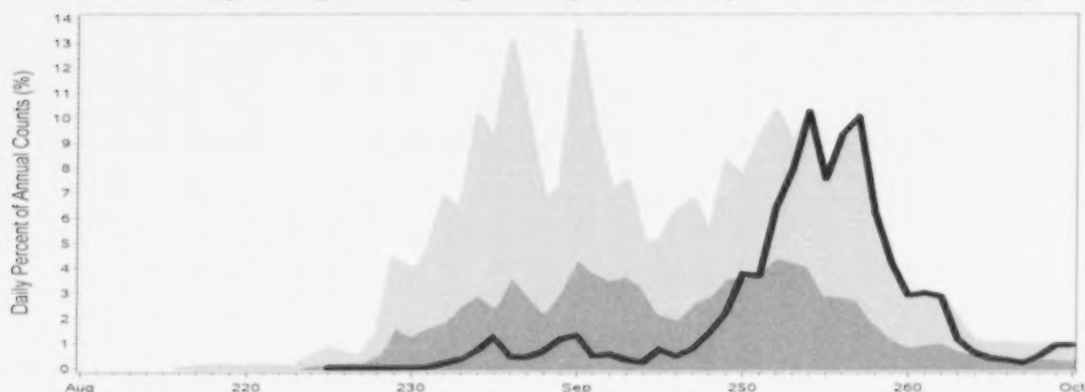
2012 Horsefly Water Temperature Observations



Appendix J. Multi-panel plots of daily Quesnel/Horsefly Sockeye migration in relation to environmental variables, by year, 1993-2015.

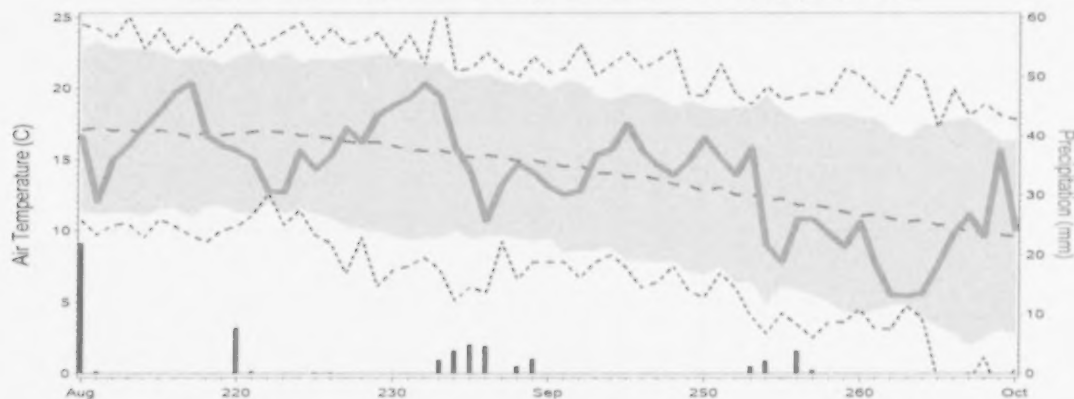
Sample plots for the year 1993 (below) display legend with vertical axis variates and horizontal axis with day of year (month label is *approximate* start of each month). Annual plots (following pages) are organized in a multi-panel format for cross-comparison of the following co-variates:

1993 LikelyBridge Average Daily Counts (Ann. Total: 23,125)

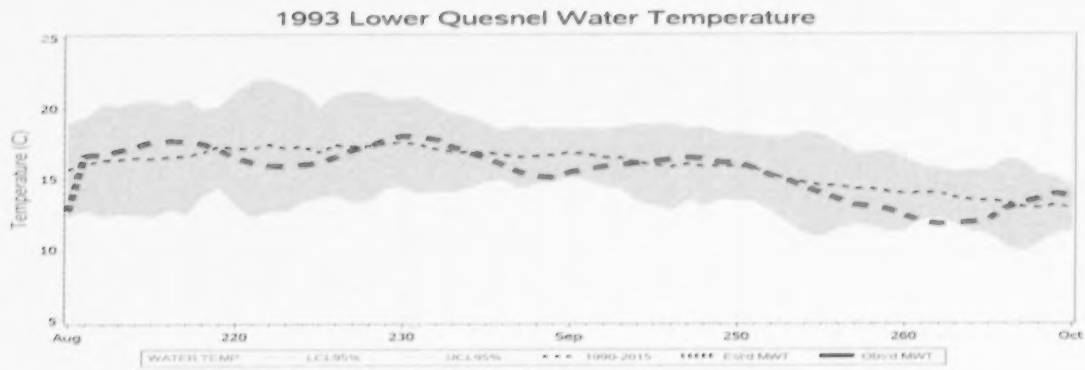


1. Daily average migrant counts ((adult + jack; black line) as a percent (%) of annual total of average daily Sockeye migrants counted at Likely Bridge, Quesnel River. Historical mean daily migration % (dark gray area) and maximum daily migration % (light gray area) derived from years 1993, 1994, 1995, 1997, 1998, 2001. Mean daily migration rates for subsequent years were obtained from expanded counts from acoustic arrays in the Quesnel River near Likely (2009, 2010, 2014, 2015), or the Horsefly River above Quesnel Lake (2005, 2006, 2007, 2010).

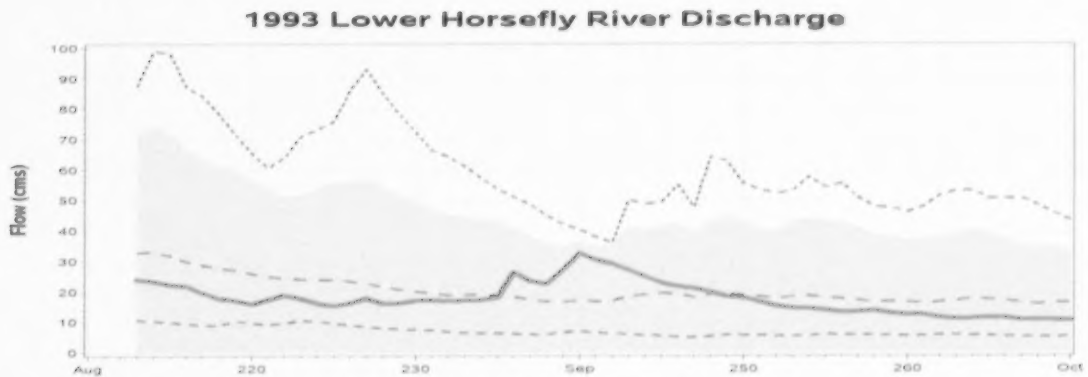
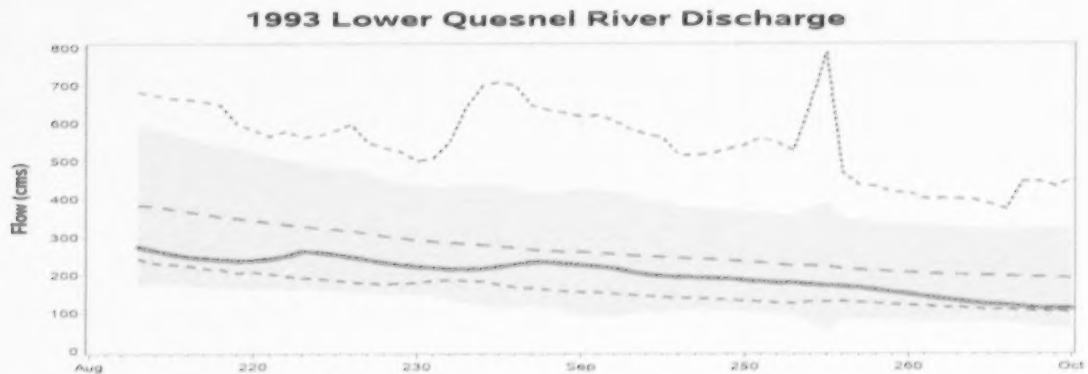
1993 Quesnel Air Temperature & Precipitation



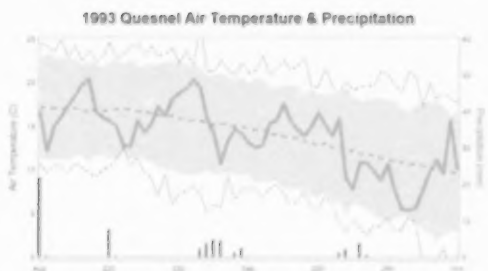
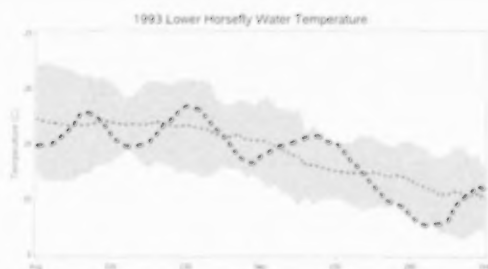
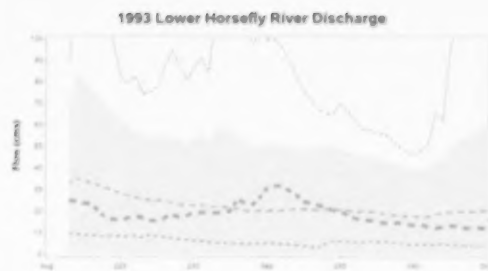
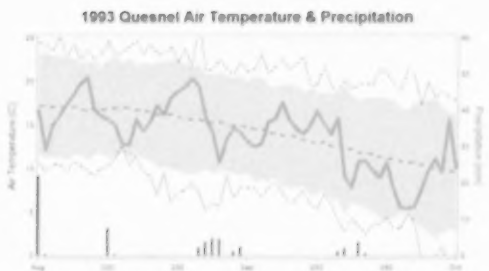
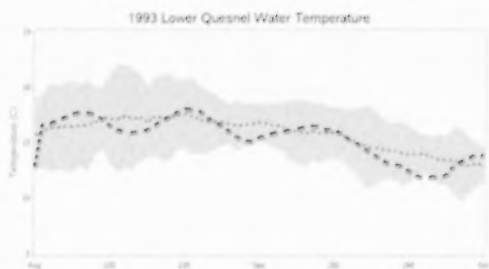
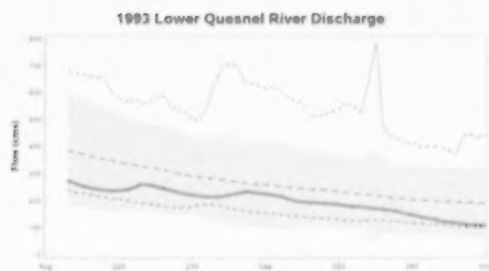
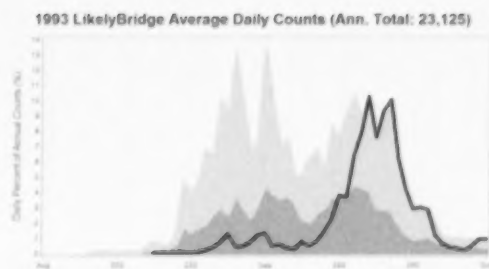
2. Observed precipitation (mm, blue bars), and regional daily mean air temperature (°C, red line) based on EC AHCCD meteorological station Quesnel (station 1096630) with historical daily mean and variance (dashed line and red area), 1900-2015.



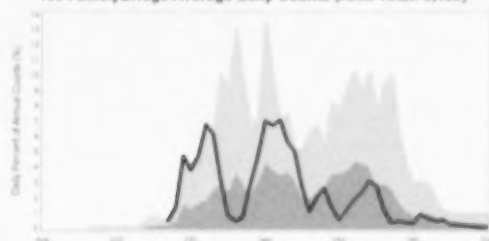
3. Observed (solid black line) and estimated (dashed blue line) daily mean water temperature in the lower Chilcotin River near Big Creek, with 1975-2012 daily mean MWT and variance (dashed line and gray area).



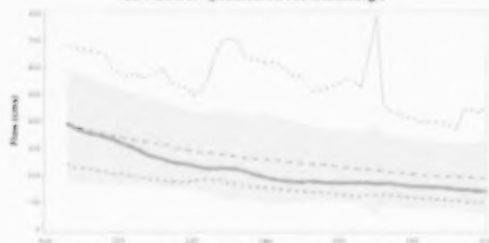
4. Daily mean discharge (cms; solid green line) at WSC stations in the lower QUESNEL RIVER NEAR QUESNEL (top), and lower HORSEFLY RIVER ABOVE QUESNEL LAKE (bottom), with historical daily mean and variance (dashed line and green area), 1901-2015.



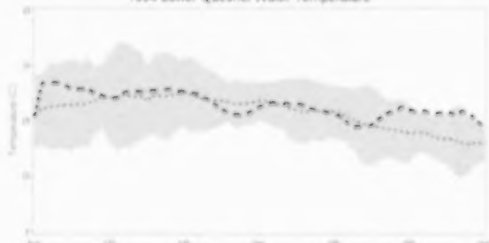
1994 LikelyBridge Average Daily Counts (Ann. Total: 6,139)



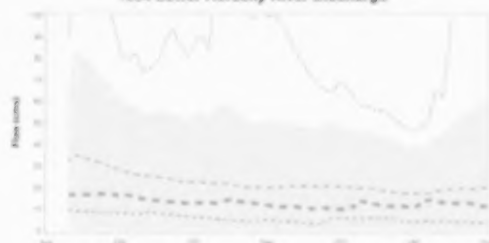
1994 Lower Quesnel River Discharge



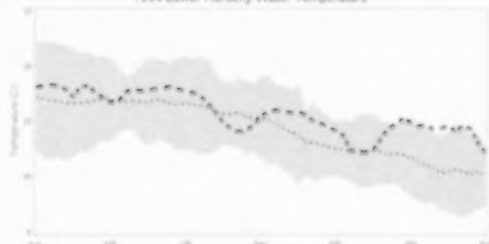
1994 Lower Quesnel Water Temperature



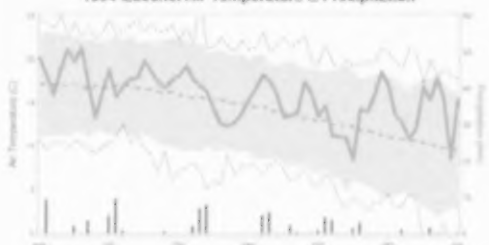
1994 Lower Horsefly River Discharge



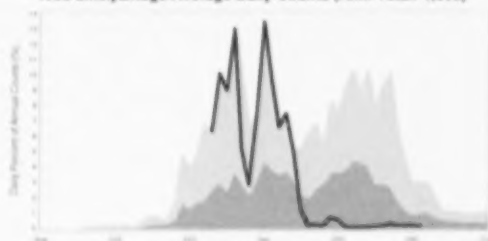
1994 Lower Horsefly Water Temperature



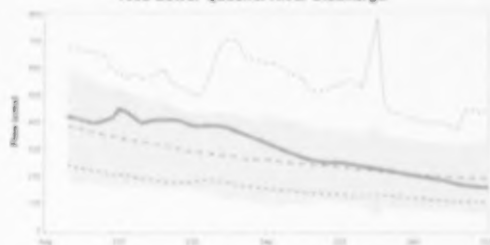
1994 Quesnel Air Temperature & Precipitation



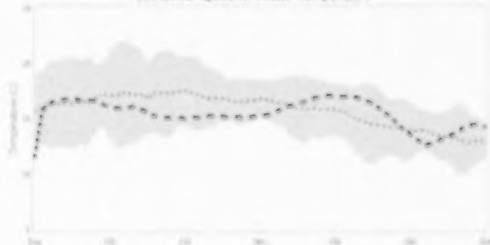
1995 Likely Bridge Average Daily Counts (Ann. Total: 1,585)



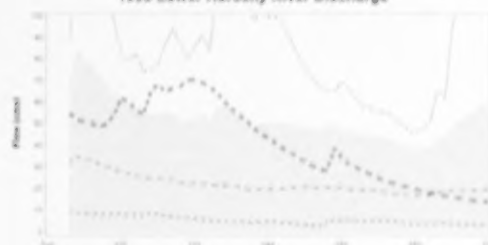
1995 Lower Quesnel River Discharge



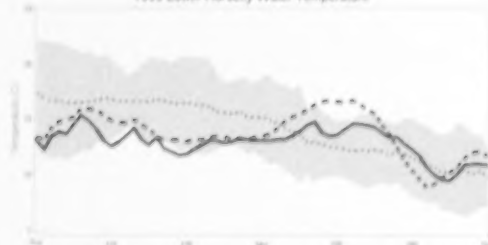
1995 Lower Quesnel Water Temperature



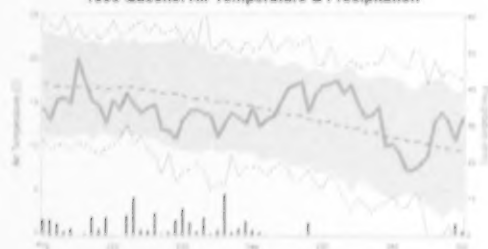
1995 Lower Horsefly River Discharge



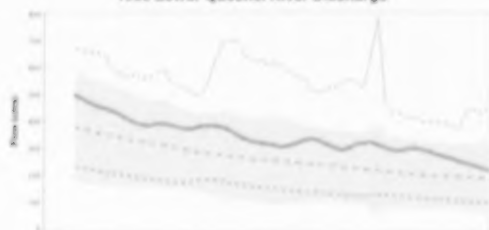
1995 Lower Horsefly Water Temperature



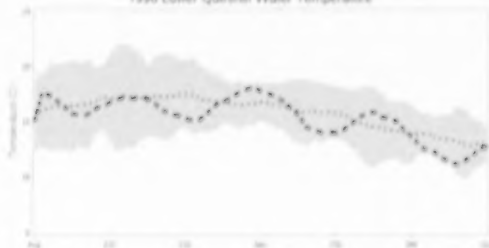
1995 Quesnel Air Temperature & Precipitation



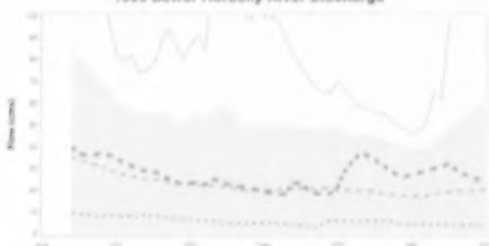
1996 Lower Quesnel River Discharge



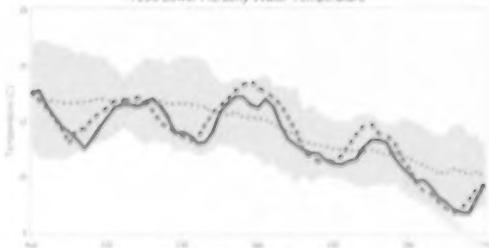
1996 Lower Quesnel Water Temperature



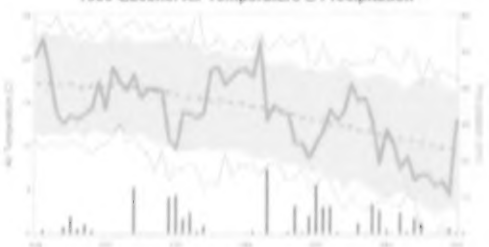
1996 Lower Horsefly River Discharge



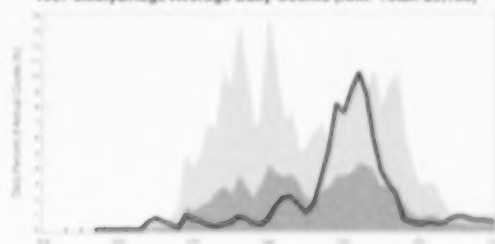
1996 Lower Horsefly Water Temperature



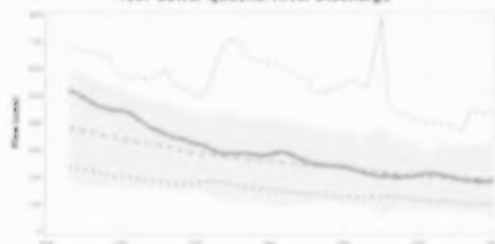
1996 Quesnel Air Temperature & Precipitation



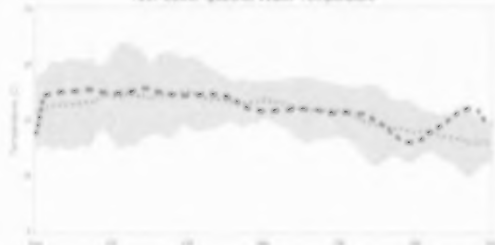
1997 LikelyBridge Average Daily Counts (Ann. Total: 29,100)



1997 Lower Quennel River Discharge



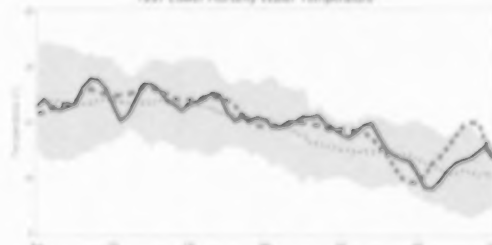
1997 Lower Quennel Water Temperature



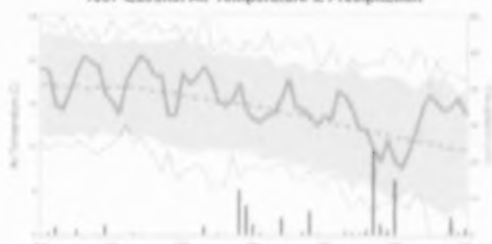
1997 Lower Horsefly River Discharge



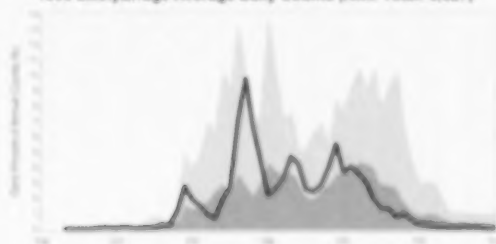
1997 Lower Horsefly Water Temperature



1997 Quennel Air Temperature & Precipitation



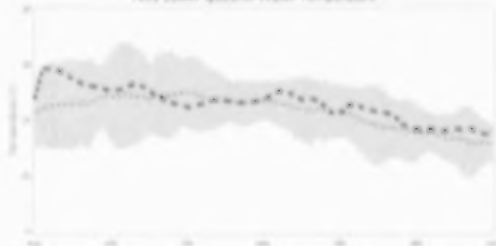
1998 LibertyBridge Average Daily Counts (Ann. Total: 5,627)



1998 Lower Quesnel River Discharge



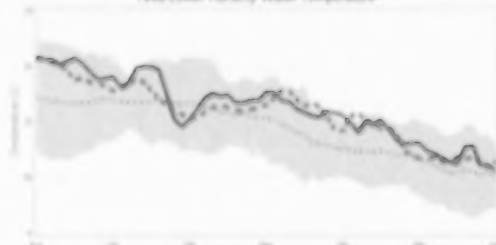
1998 Lower Quesnel Water Temperature



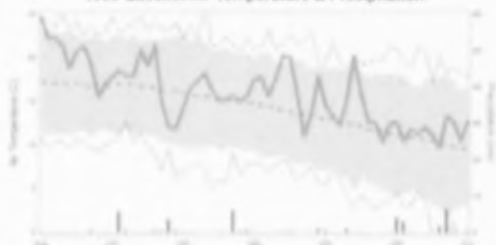
1998 Lower Horsefly River Discharge



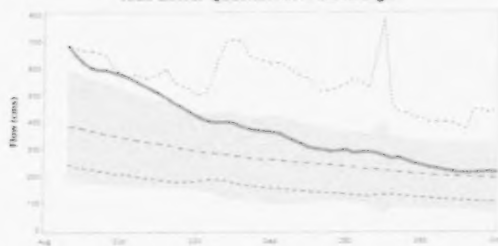
1998 Lower Horsefly Water Temperature



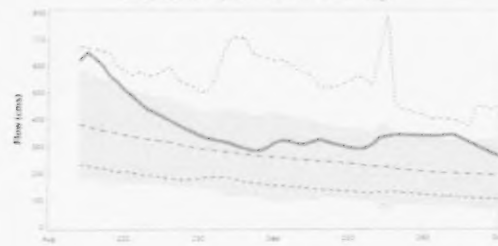
1998 Quesnel Air Temperature & Precipitation



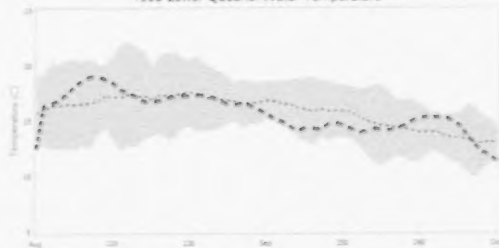
1999 Lower Quesnel River Discharge



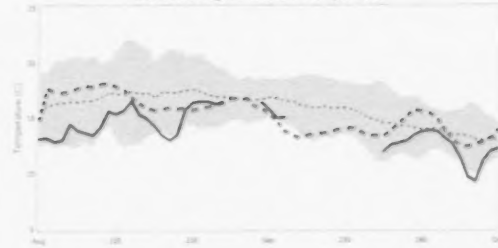
2000 Lower Quesnel River Discharge



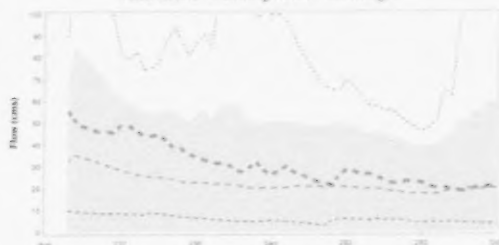
1999 Lower Quesnel Water Temperature



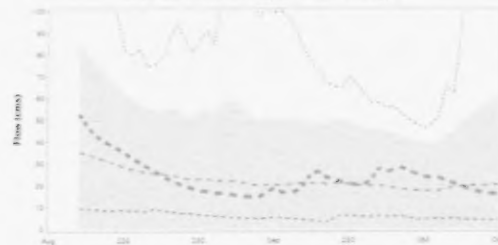
2000 Lower Quesnel Water Temperature



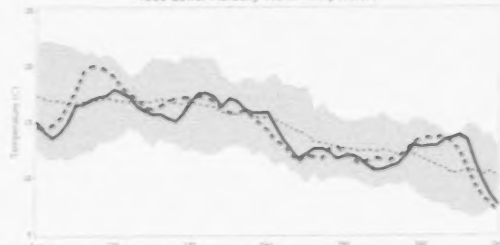
1999 Lower Horsefly River Discharge



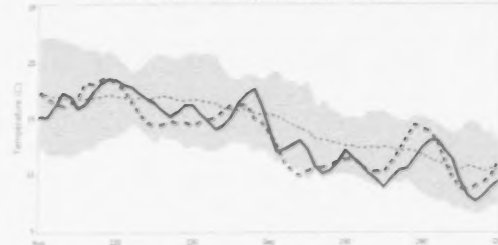
2000 Lower Horsefly River Discharge



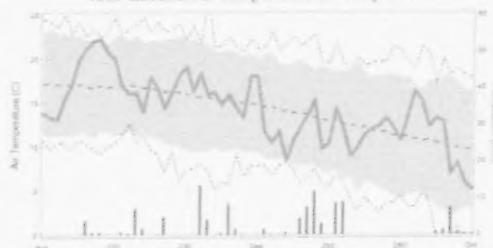
1999 Lower Horsefly Water Temperature



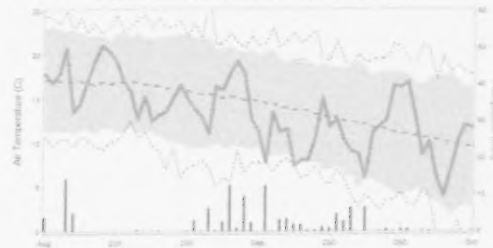
2000 Lower Horsefly Water Temperature



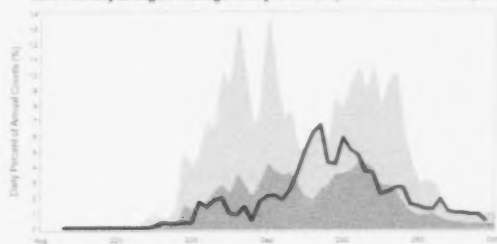
1999 Quesnel Air Temperature & Precipitation



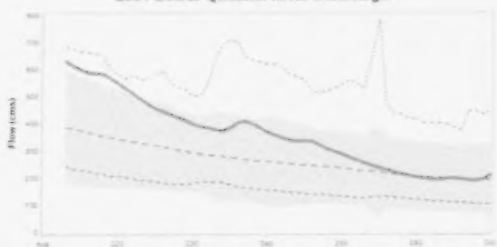
2000 Quesnel Air Temperature & Precipitation



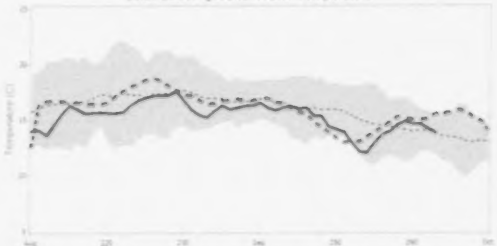
2001 LikelyBridge Average Daily Counts (Ann. Total: 31,133)



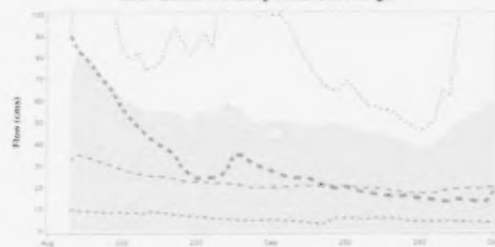
2001 Lower Quesnel River Discharge



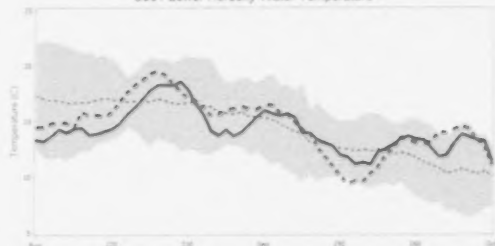
2001 Lower Quesnel Water Temperature



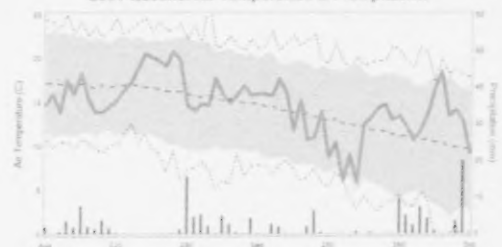
2001 Lower Horsefly River Discharge

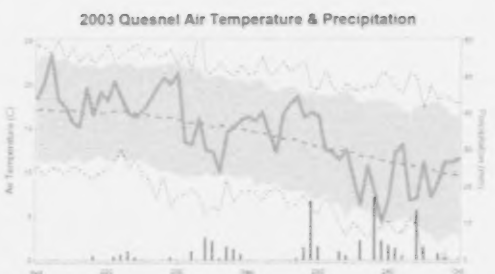
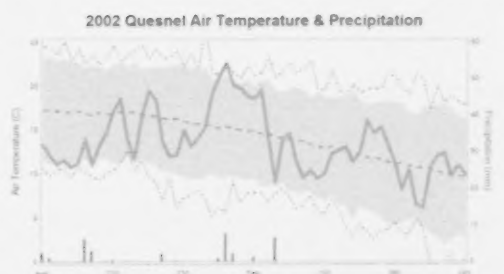
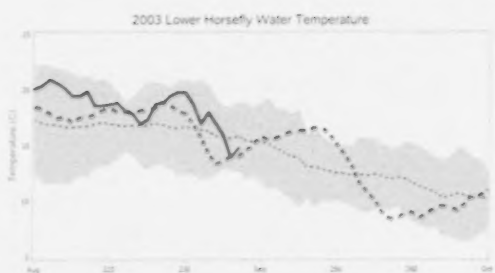
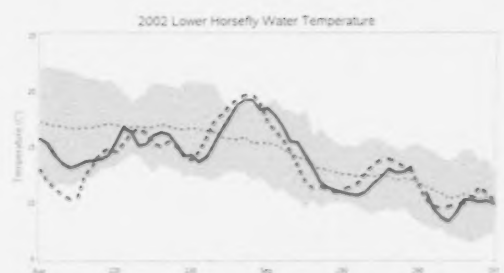
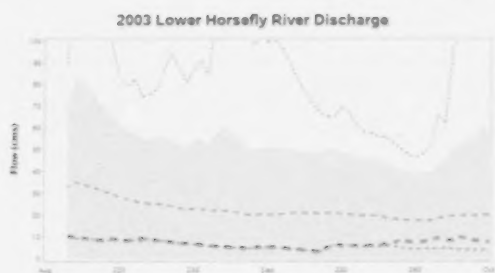
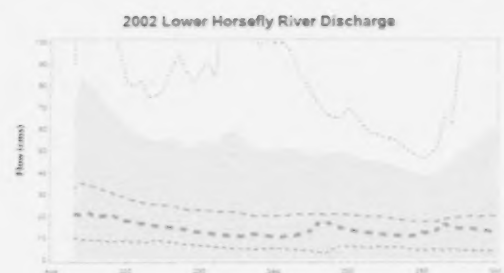
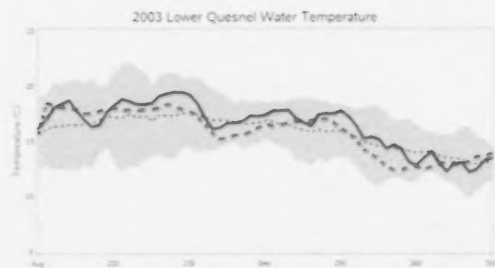
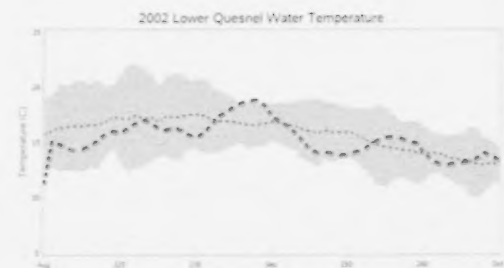
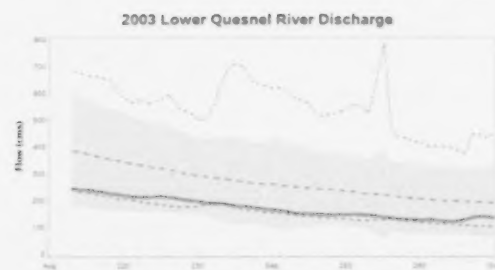
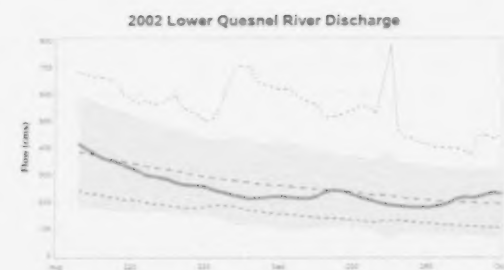


2001 Lower Horsefly Water Temperature

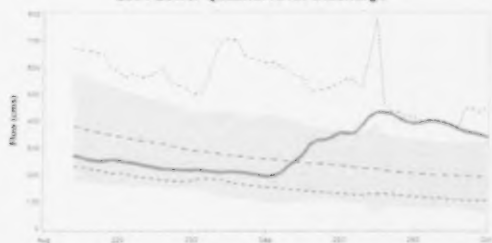


2001 Quesnel Air Temperature & Precipitation

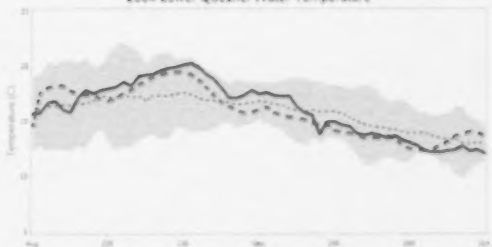




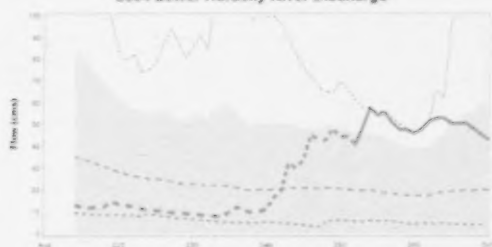
2004 Lower Quesnel River Discharge



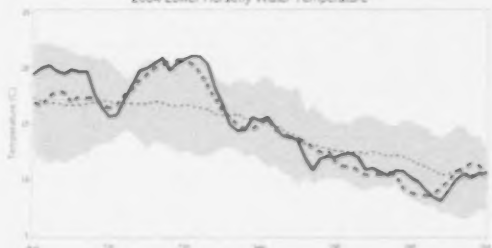
2004 Lower Quesnel Water Temperature



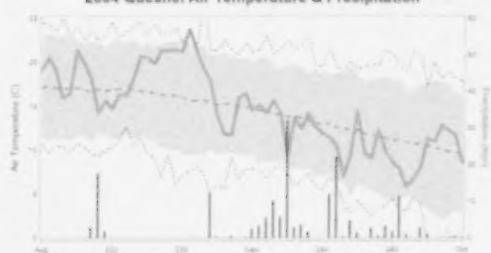
2004 Lower Horsefly River Discharge

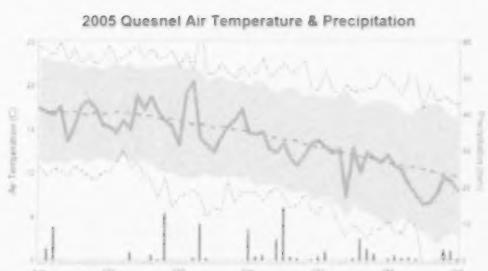
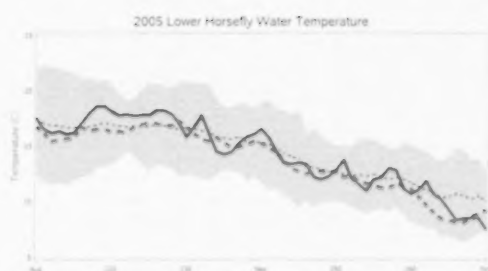
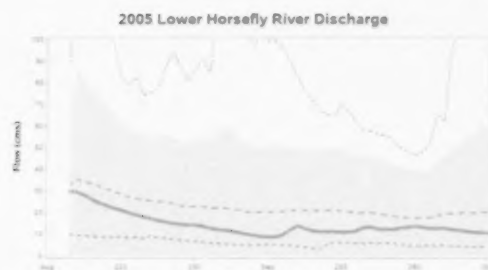
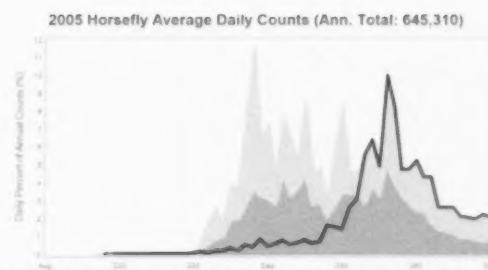
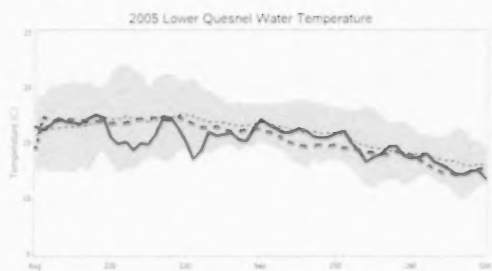
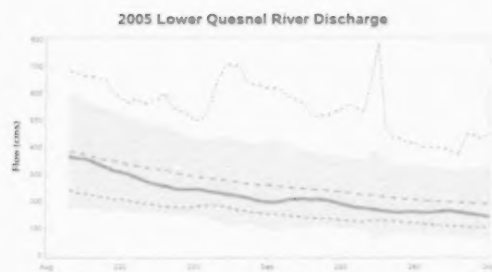


2004 Lower Horsefly Water Temperature

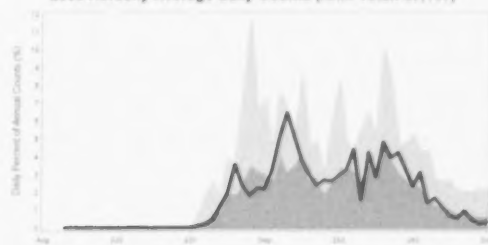


2004 Quesnel Air Temperature & Precipitation

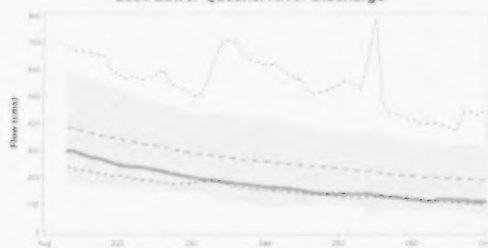




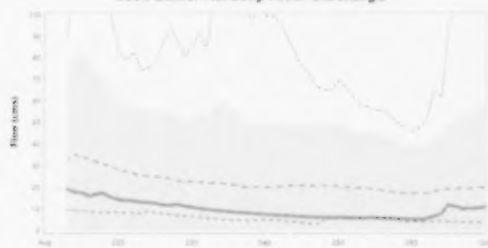
2006 Horsefly Average Daily Counts (Ann. Total: 87,167)



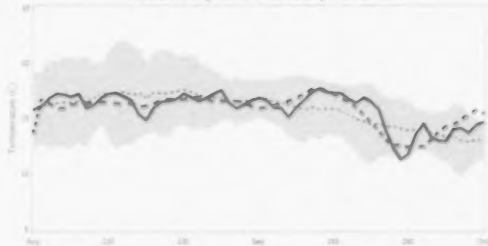
2006 Lower Quesnel River Discharge



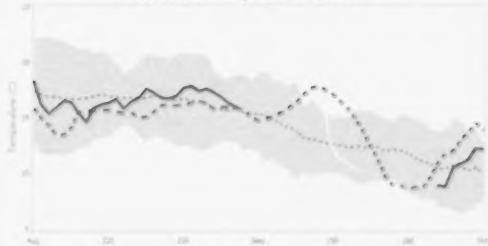
2006 Lower Horsefly River Discharge



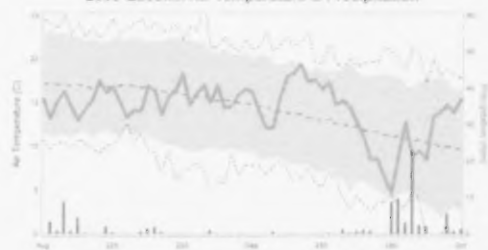
2006 Lower Quesnel Water Temperature

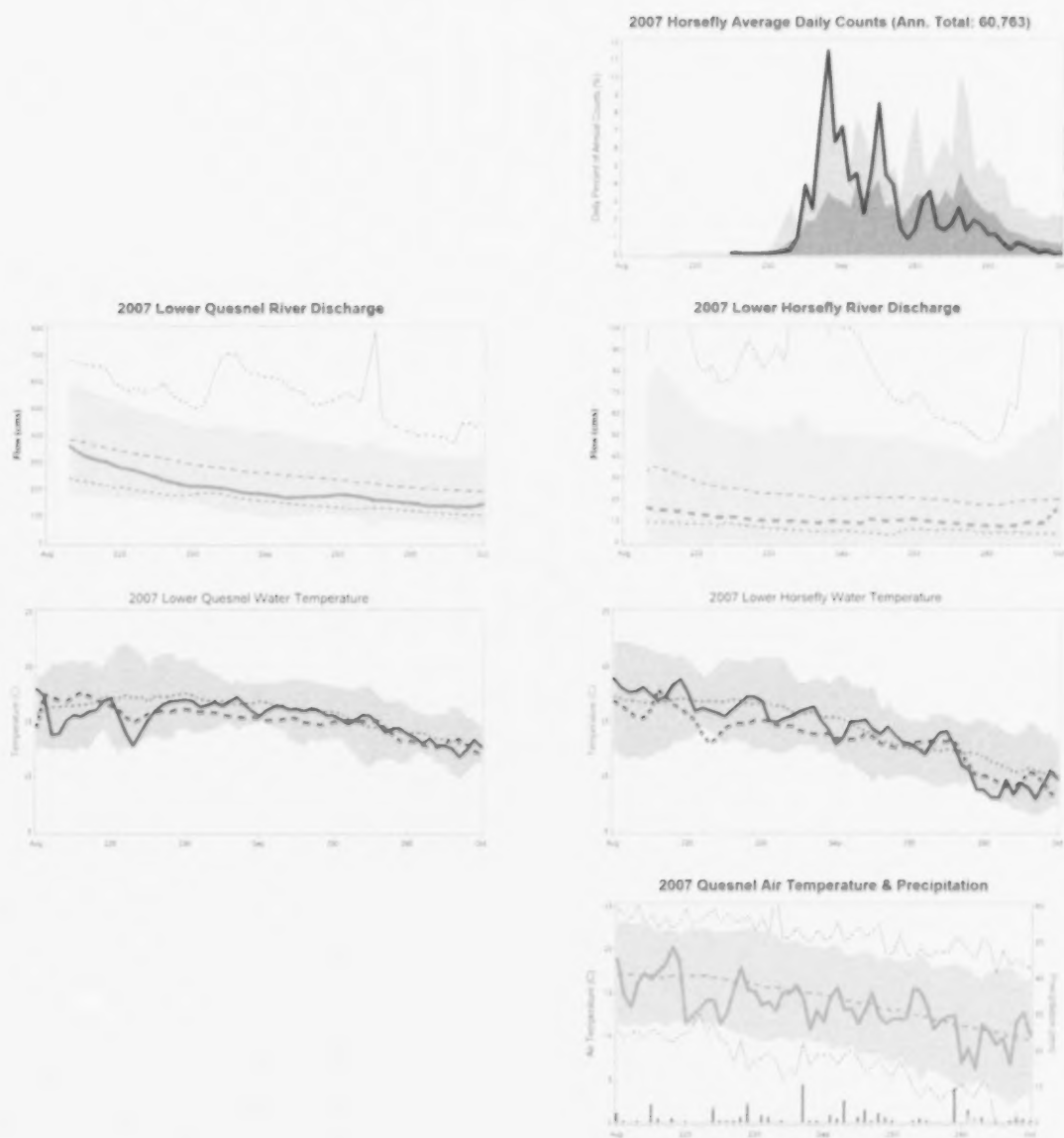


2006 Lower Horsefly Water Temperature

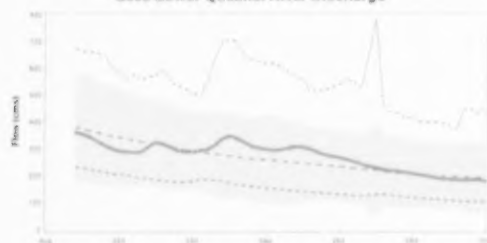


2006 Quesnel Air Temperature & Precipitation

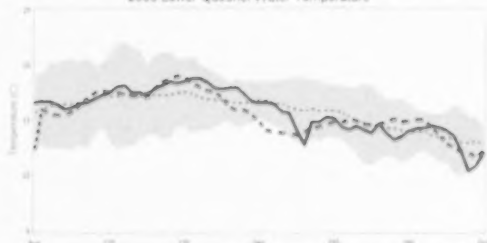




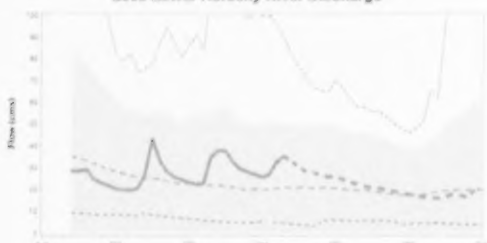
2008 Lower Quesnel River Discharge



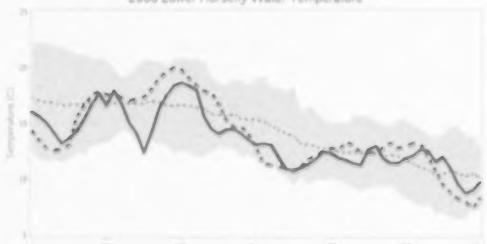
2008 Lower Quesnel Water Temperature



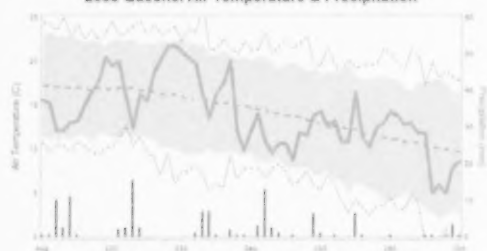
2008 Lower Horsefly River Discharge



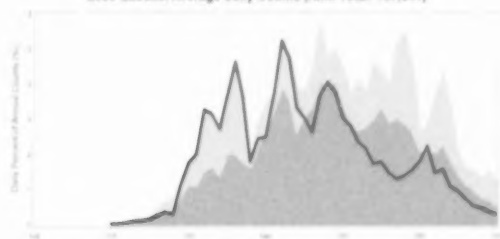
2008 Lower Horsefly Water Temperature



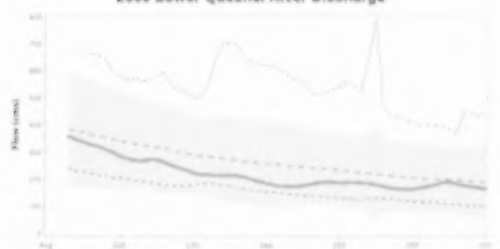
2008 Quesnel Air Temperature & Precipitation



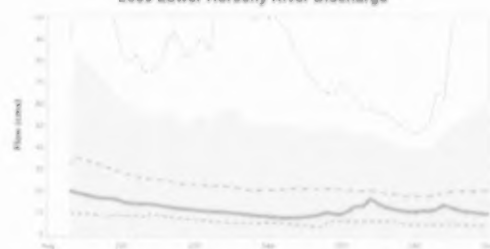
2009 Quesnel Average Daily Counts (Ann. Total: 157,541)



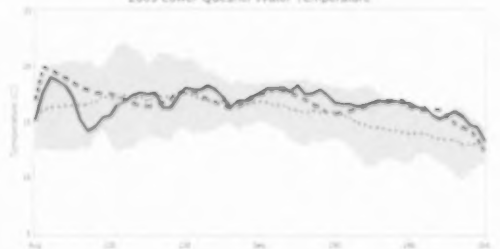
2009 Lower Quesnel River Discharge



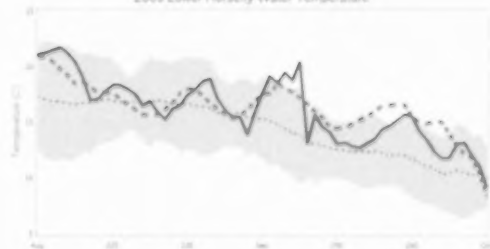
2009 Lower Horsefly River Discharge



2009 Lower Quesnel Water Temperature



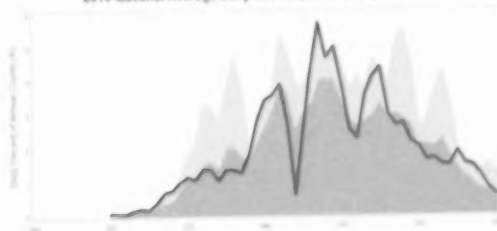
2009 Lower Horsefly Water Temperature



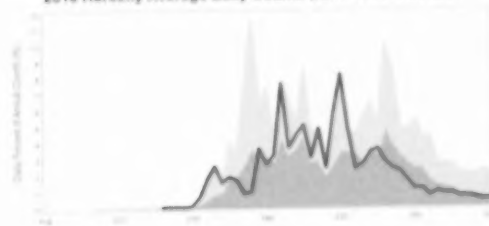
2009 Quesnel Air Temperature & Precipitation



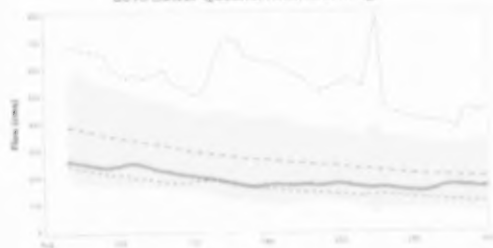
2010 Quesnel Average Daily Counts (Ann. Total: 269,142)



2010 Horsefly Average Daily Counts (Ann. Total: 152,167)



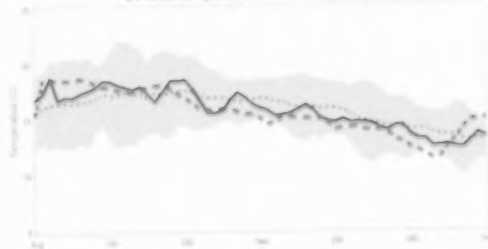
2010 Lower Quesnel River Discharge



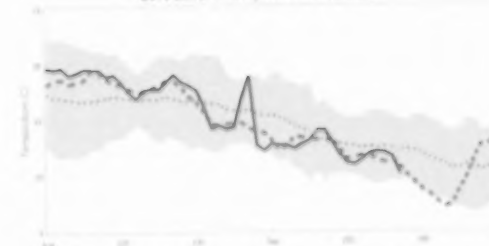
2010 Lower Horsefly River Discharge



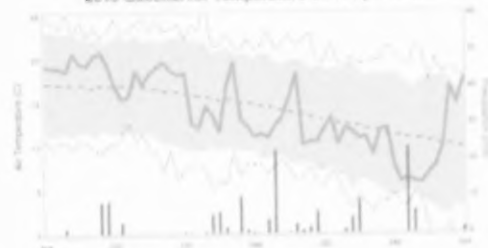
2010 Lower Quesnel Water Temperature



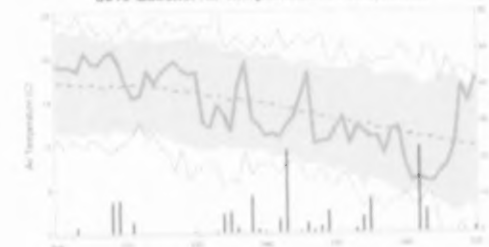
2010 Lower Horsefly Water Temperature



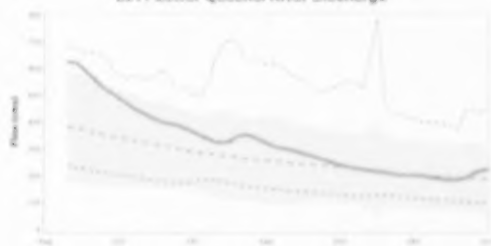
2010 Quesnel Air Temperature & Precipitation



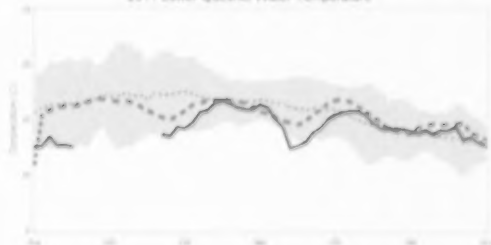
2010 Horsefly Air Temperature & Precipitation



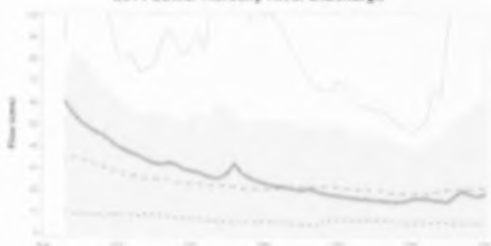
2011 Lower Quesnel River Discharge



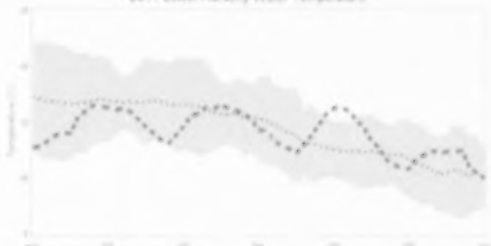
2011 Lower Quesnel Water Temperature



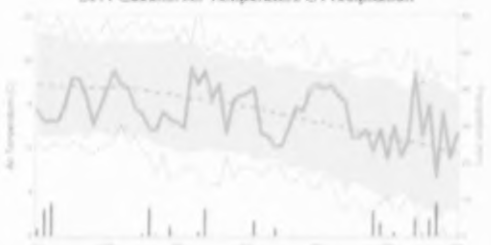
2011 Lower Horsefly River Discharge



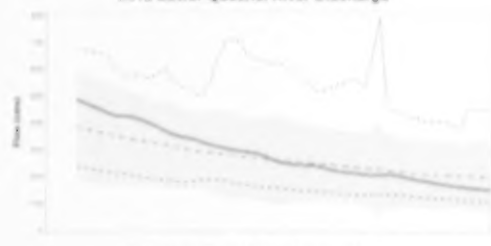
2011 Lower Horsefly Water Temperature



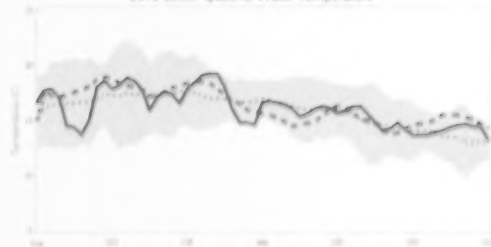
2011 Quesnel Air Temperature & Precipitation



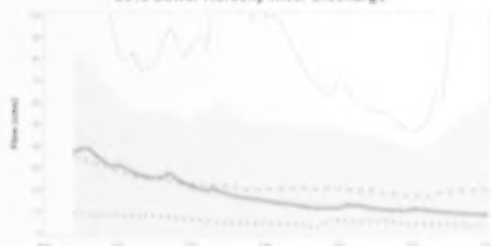
2012 Lower Quesnel River Discharge



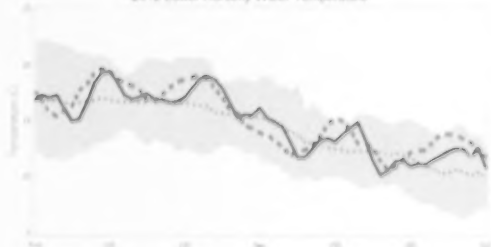
2012 Lower Quesnel Water Temperature



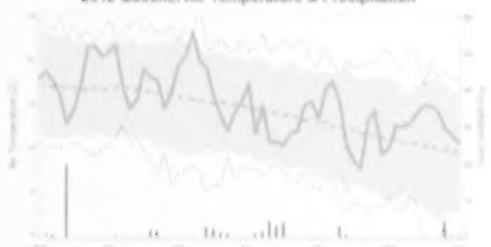
2012 Lower Horsefly River Discharge

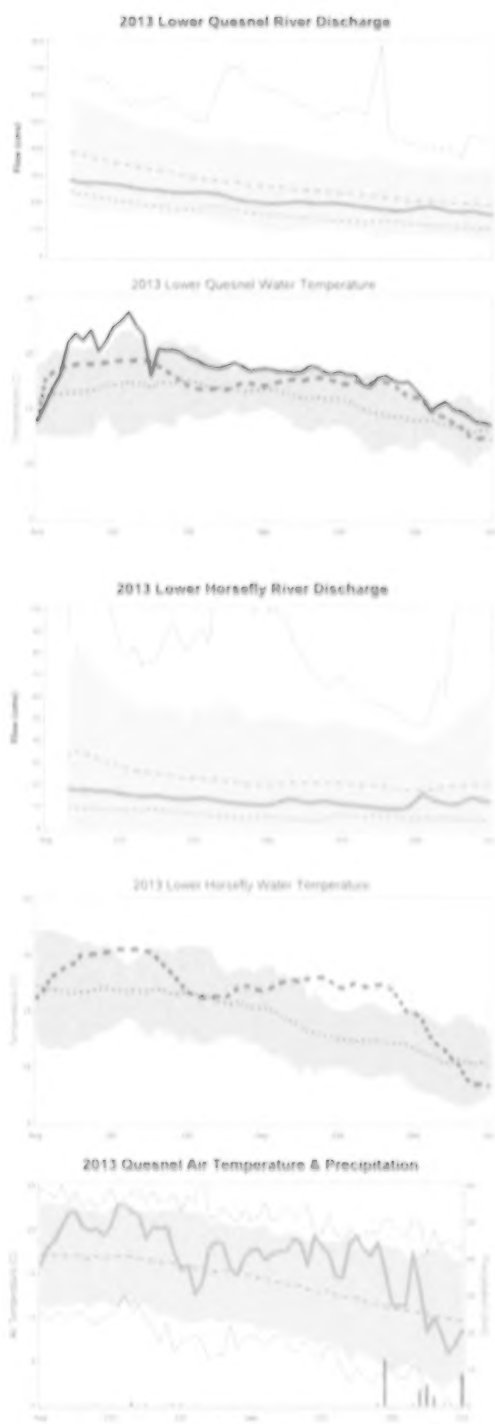


2012 Lower Horsefly Water Temperature

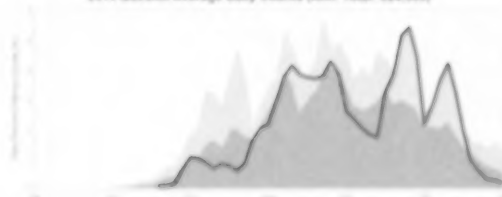


2012 Quesnel Air Temperature & Precipitation

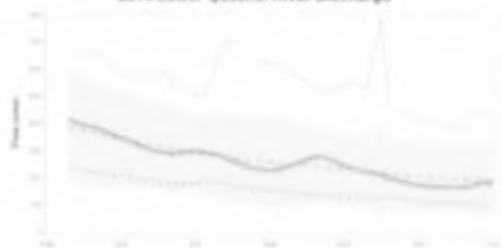




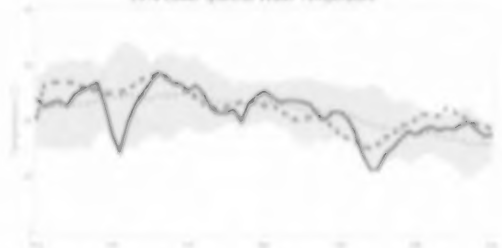
2014 Quesnel Average Daily Counts (Ann. Total: 824,309)



2014 Lower Quesnel River Discharge



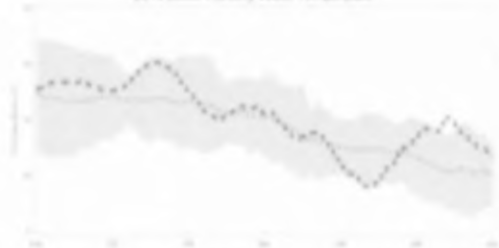
2014 Lower Quesnel Water Temperature



2014 Lower Horsefly River Discharge



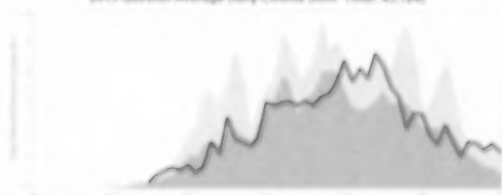
2014 Lower Horsefly Water Temperature



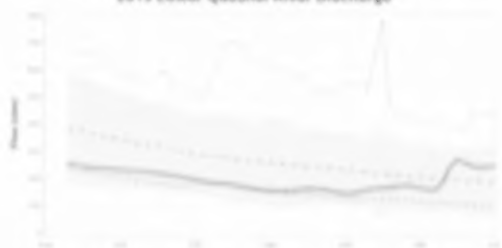
2014 Quesnel Air Temperature & Precipitation



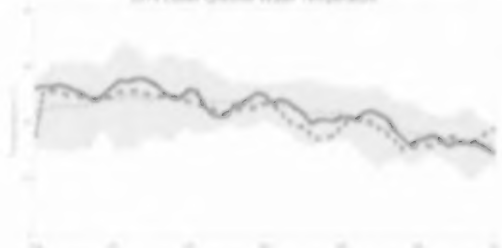
2015 Quesnel Average Daily Counts (Ave. Total: 45,126)



2015 Lower Quesnel River Discharge



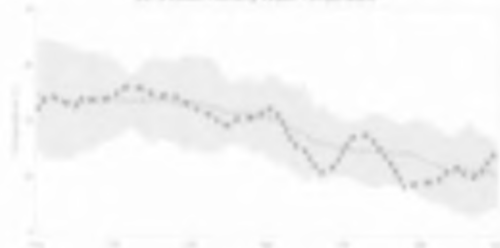
2015 Lower Quesnel Water Temperature



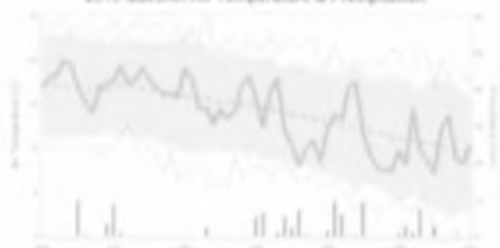
2015 Lower Horsefly River Discharge



2015 Lower Horsefly Water Temperature



2015 Quesnel Air Temperature & Precipitation



Appendix K. Annual anomaly plots for Quesnel Sockeye daily migration lagged 4 days earlier to align with water temperature (estimated), and discharge (observed & estimated) in the lower Quesnel River.

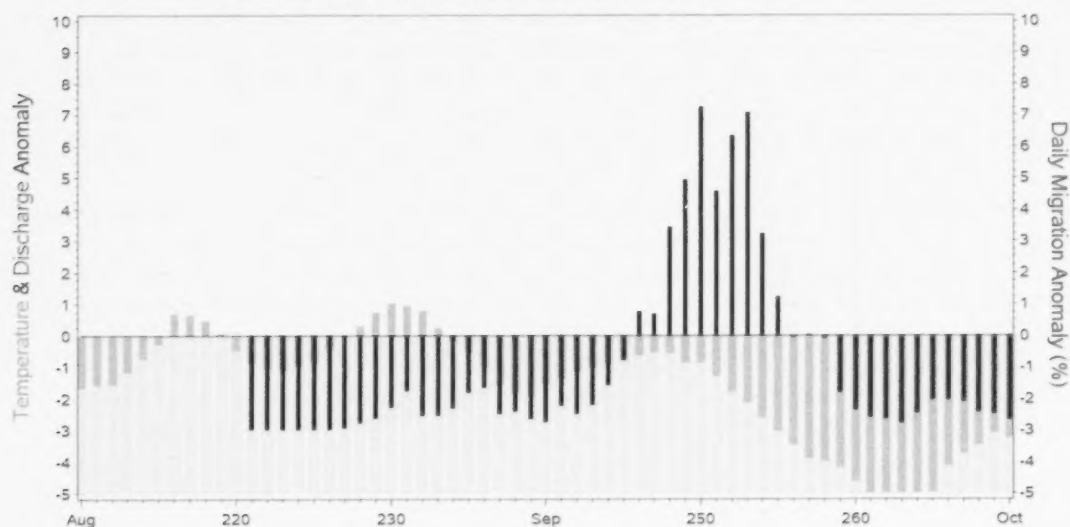
Zero-line thresholds:

- Daily migration rate = 3.0% (75th percentile of non-zero daily migration rates (1994-2015);
- Water temperature = 17°C (~75th percentile);
- Discharge = 350 cms (~75th percentile).

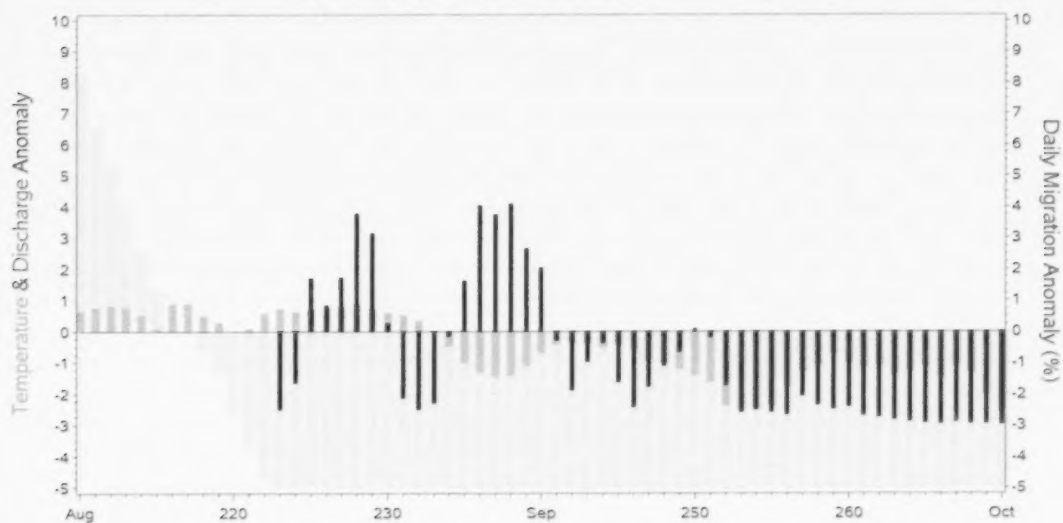
To read the plot: environmental variate anomalies are read from the primary y-axis; migration anomalies are read from the secondary y-axis.

1. Black bars are the daily migration rate (%) minus the 3% threshold (e.g. 5% is represented as 2% on the secondary y-axis (5-3 = +2)).
2. Red bars are the estimated daily mean water temperature minus the 17°C threshold (e.g. 16°C → -1 since 16-17 = -1).
3. Blue bars are the observed daily discharge minus the 350 cms threshold, and divided by 10 to fit the axis (e.g. 350 cms → (300-350)/10 = -5).

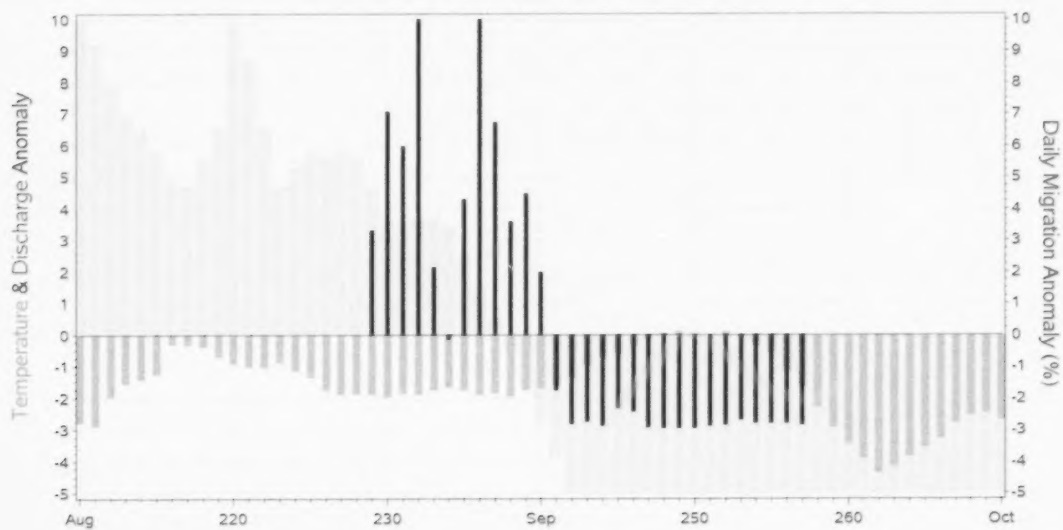
1993 Quesnel Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 15.3c Total Migrants: 23124.75
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m3/s



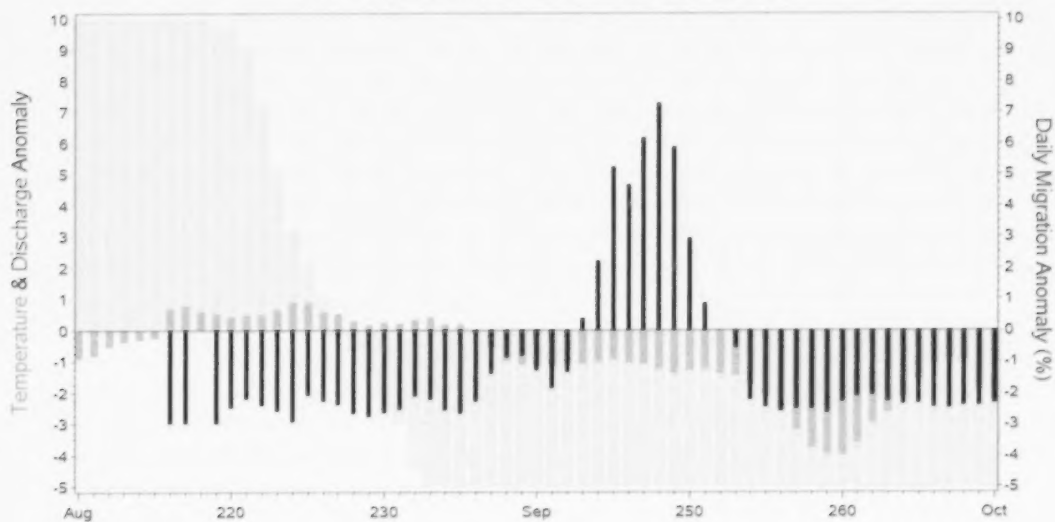
1994 Quesnel Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Aug-Sep MWT: 16.2c Total Migrants: 6139.333333
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m³/s



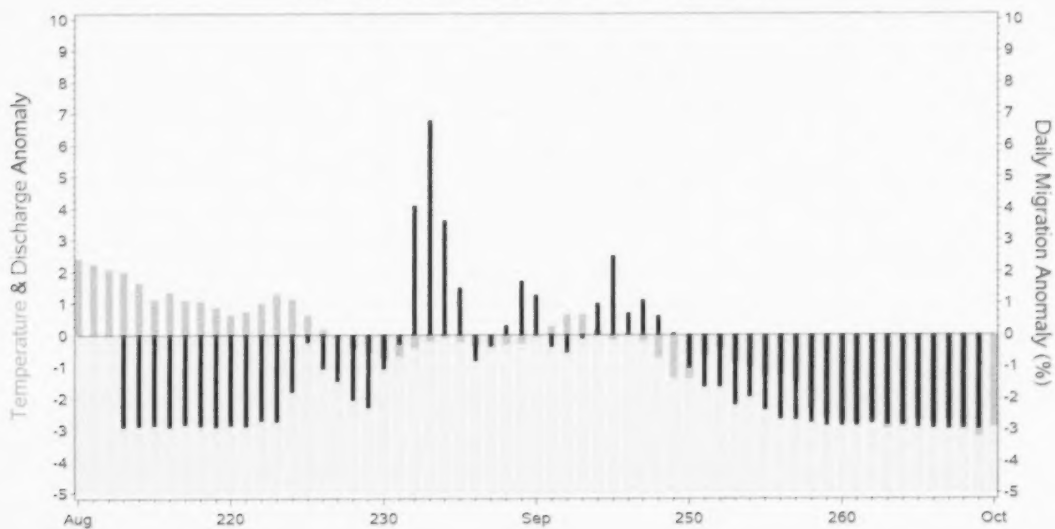
1995 Quesnel Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Aug-Sep MWT: 15.2c Total Migrants: 1584.6190476
Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m³/s



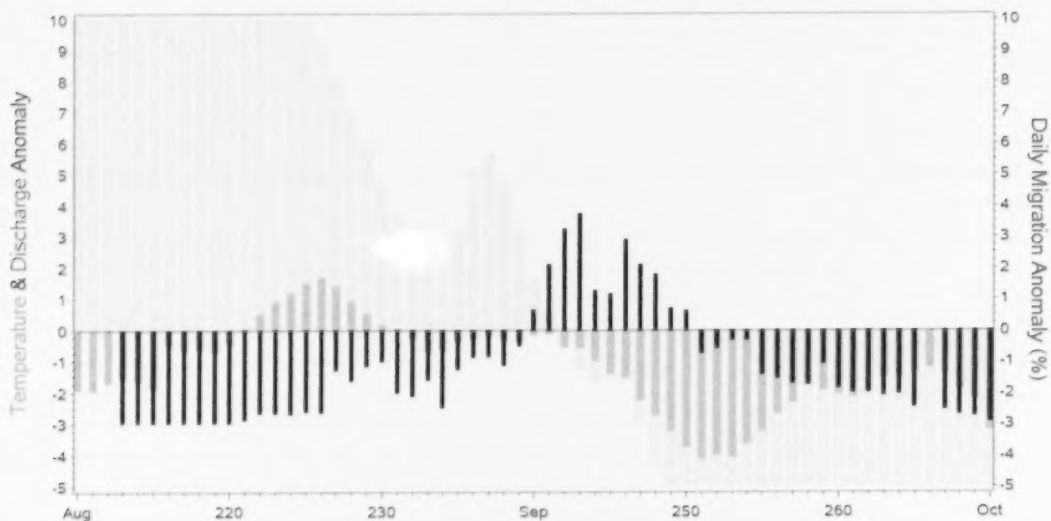
1997 Quesnel Sockeye Migration Conditions: PDO/ENSO: Warm/Neutral Aug-Sep MWT: 15.9c Total Migrants: 29099.821429
 Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m³/s



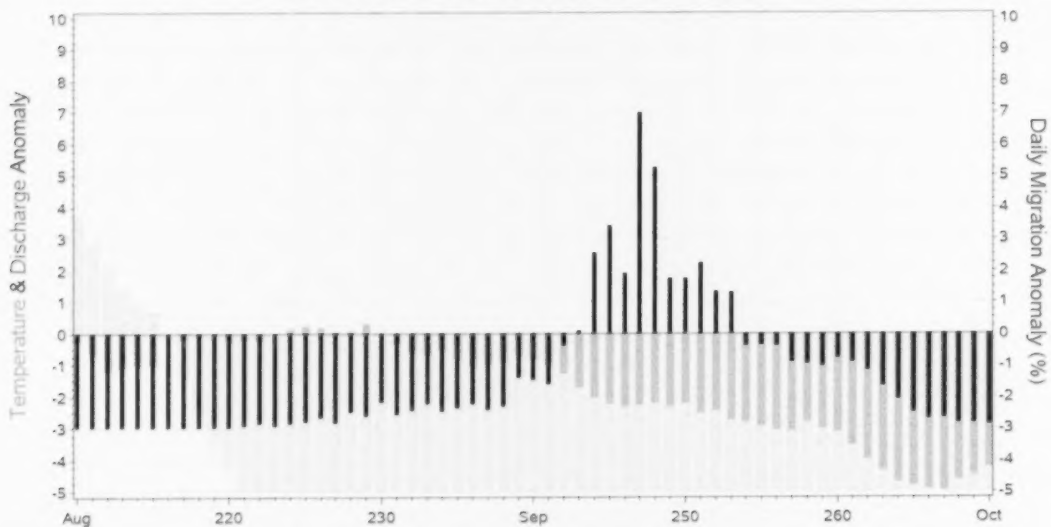
1998 Quesnel Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 16.3c Total Migrants: 5626.875
 Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m³/s



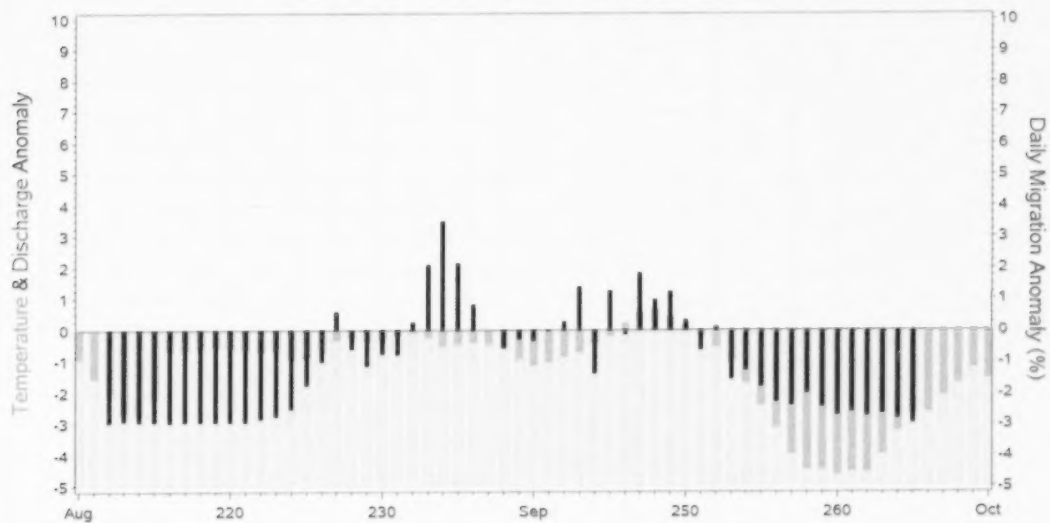
2001 Quesnel Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Aug-Sep MWT: 15.6c Total Migrants: 31133.375
 Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m³/s



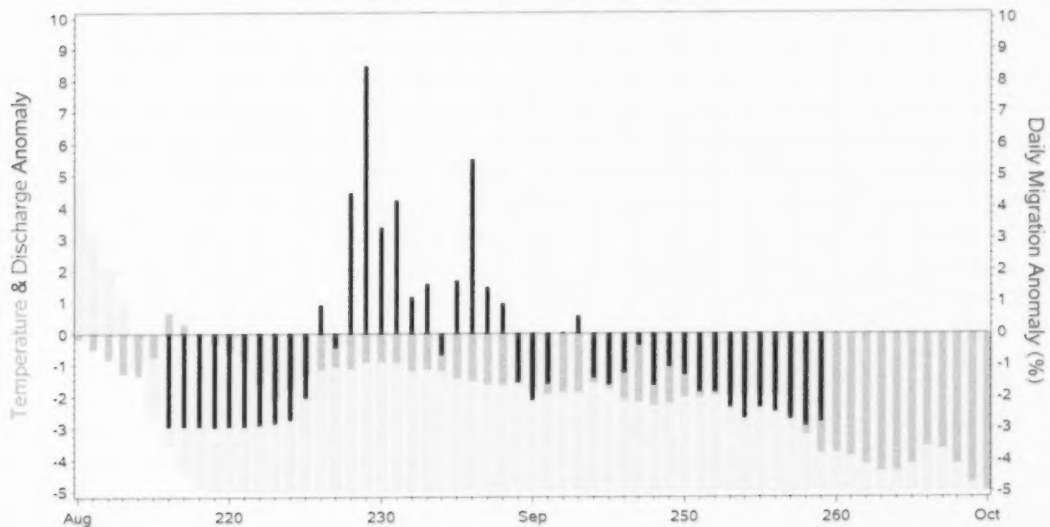
2005 Quesnel Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 15.1c Total Migrants: 645309.80073
 Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m³/s



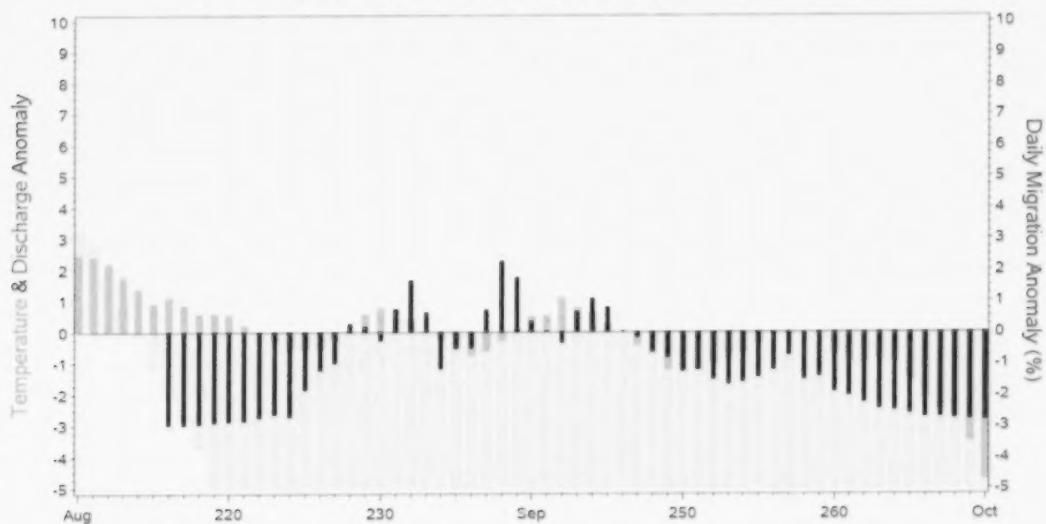
2006 Quesnel Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Aug-Sep MWT: 15.5c Total Migrants: 87167.32898
 Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m³/s



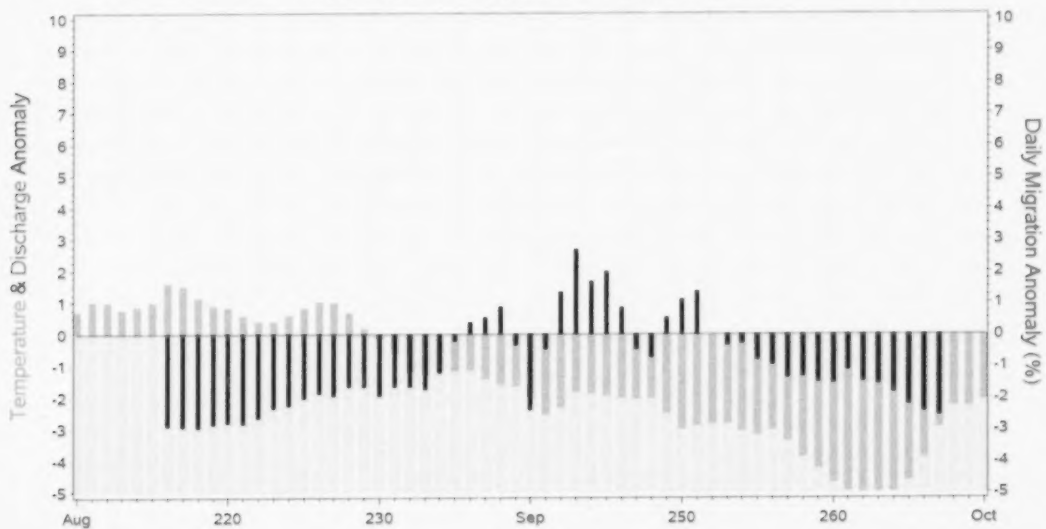
2007 Quesnel Sockeye Migration Conditions: PDO/ENSO: Cool/Warm Aug-Sep MWT: 14.8c Total Migrants: 60762.542844
 Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m³/s



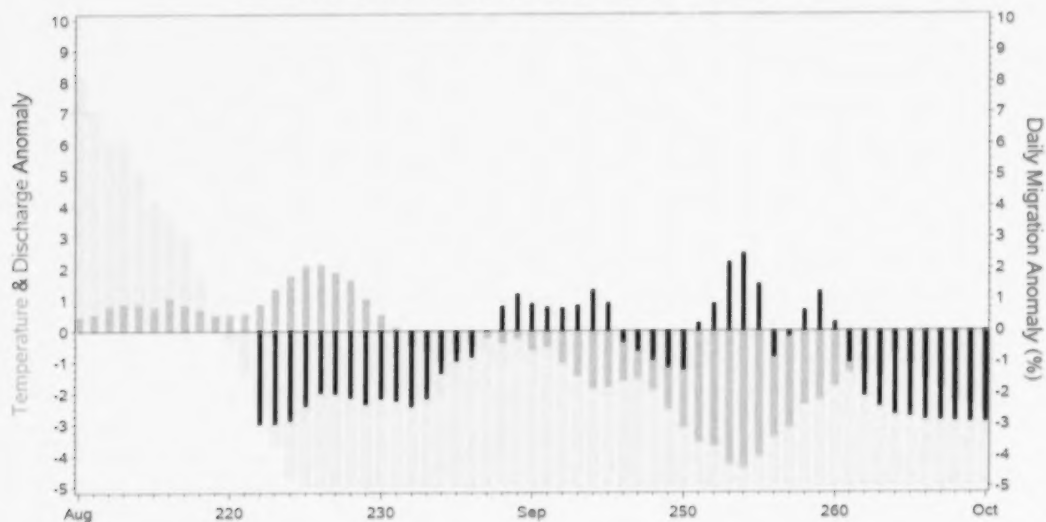
2009 Quesnel Sockeye Migration Conditions: PDO/ENSO: Cool/Neutral Aug-Sep MWT: 16.5c Total Migrants: 157541.30841
 Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m3/s



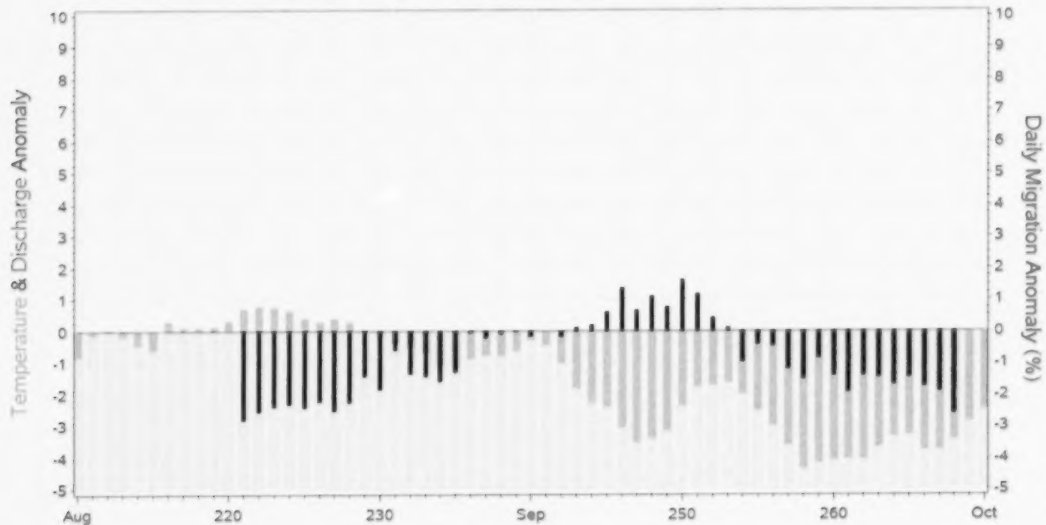
2010 Quesnel Sockeye Migration Conditions: PDO/ENSO: Warm/Warm Aug-Sep MWT: 15.4c Total Migrants: 269141.75
 Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m3/s



2014 Quesnel Sockeye Migration Conditions: PDO/ENSO: 2014/Unknown Aug-Sep MWT: 16.0c Total Migrants: 824309
 Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m³/s



2015 Quesnel Sockeye Migration Conditions: PDO/ENSO: 2015/Unknown Aug-Sep MWT: 15.4c Total Migrants: 43124
 Zero-Line Thresholds: Daily Migrants: 3.0% MWT: 17c Flow: 350 m³/s



Appendix L. History and function of the McKinley Lake Siphon.

In 1969, IPSFC⁸⁵ personnel built McKinley Dam at the outlet of McKinley Lake (Figure 4) with a siphon system to deliver ~2°C cooler water from the lake hypolimnion to Horsefly River spawning grounds via McKinley Creek (Mead 1969; Cooper 1973). This was an effort to reduce pre-spawn Sockeye mortality and bacterial infection associated with elevated water temperatures (Rood & Hamilton 1995; Holmes 2009).

The dam was designed with an initial target minimum flow of 0.85 cms, and 1.4 cms at the McKinley Creek gauging station ~1 km below McKinley Lake, and a target water temperature of not more than 11°C below the dam and not more than 14°C above the McKinley/Horsefly confluence during Sockeye spawning (McNally 1986). The control structure consists of a concrete base with piers and gates to regulate the surface discharge from the lake when temperature control was required for downstream spawners. A small weir and pool fishway at the east end of the structure allowed for the passage of salmon and trout when the gates are closed. A 66-inch (168 cm) diameter pipe extending 732 m into the lake from the control structure supplied deep lake water to a diffusion chamber adjacent to the fishway, designed to mix hypolimnetic and surface waters for release into McKinley Creek in order to cool spawning grounds in the upper Horsefly River (Rood & Hamilton 1995; Holmes 2009). Control gates in the fishway and at the outlet of the deep lake pipe provided regulation of flows through these facilities (McNally 1986). When not in use, the gates could be fully withdrawn to allow for normal lake discharge to the creek, and fish passage enabled through the open fishway.⁸⁶

While utilized extensively during dominant and sub-dominant cycle lines during the 1980s and 1990s⁸⁷, the system largely fell out of use as of 2004/2005, for a variety of reasons (pers. comm., Doug Turvey, Spius Creek Hatchery Manager, DFO/SEP, 1994-2015). The project experienced mixed success, as severe bacterial disease outbreaks frequently re-occurred in subsequent years (MacDonald et al. 2000b). In some years, competing water resource requirements for other fish species (under provincial jurisdiction) led to in-season changes to minimum flow targets, largely reducing the utility of the McKinley flow control system for Sockeye spawning purposes (pers. comm., Doug Turvey). Diminishing water supply over the decades due to changing weather patterns in the McKinley watershed may also have contributed to the reduced utility of the control structure (pers. comm., Rick Holmes, contract operator, Horsefly Spawning Channel). In the early 2000s, DFO personnel recognized that there was insufficient storage capacity for this system to effectively mitigate downstream water temperatures by the time of arrival of Sockeye spawners, after meeting minimum McKinley Creek flow requirements for other species (pers. comm., Judy Hillaby, Rick Holmes), and studies indicated that the temperature-moderating capacity of the McKinley Lake siphon discharge was largely restricted to McKinley Creek, and undetectable in the lower Horsefly River (MacDonald et al. 2000b).

In recent years, the McKinley flow control structure was used in 2014 to assist with water quality for fish arrivals potentially stressed from Mount Polley mine tailings pond failure (Petticrew et al. 2015). Currently the control gates are fully withdrawn to allow for normal lake discharge to the creek, and fish passage is enabled through the open fishway.

⁸⁵ International Pacific Salmon Fisheries Commission

⁸⁶ The McKinley Dam flow control structure was operated by the Quesnel River Hatchery from 1982 until the hatchery's closure in 1994 (pers. comm., Doug Lofthouse, Regional Enhancement Biologist, DFO/OHEB). Responsibility was transferred to Fulton River Spawning Channel personnel until 2006/2007 and Spius Creek Hatchery personnel thereafter (pers. comm., Judy Hillaby, Restoration Biologist, DFO, Horsefly, B.C.).

⁸⁷ Due to budget constraints in the DFO Salmon Enhancement Program, siphon operations since the 1980s were restricted to the years of high escapement, i.e. dominant and sub-dominant cycle lines, where more than 100,000 spawners were anticipated (pers. comm., Doug Turvey).